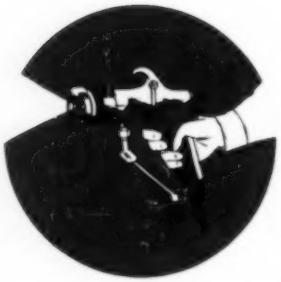
JANUARY 1952

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

here's how CELLOSOLVE® SOLVENT increases sales and profits



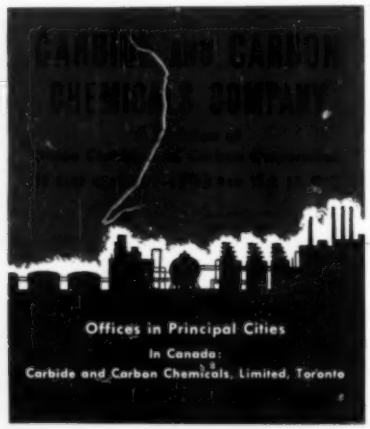
Let CELLOSOLVE solvent help you...

In surface coatings . . . CELLOSOLVE solvent is an important medium-boiling solvent in nitrocellulose lacquers and phenolic varnishes. Its use imparts improved flow out and helps give you glossy, durable finishes.

As a solvent for dyestuffs . . . CELLOSOLVE solvent is important in the production of textiles, leather, duplicating fluids, and printing inks. It is a coupler that increases the solubility of textile dyes and gives you brighter shades. When you use it in dyeing leather, CELLOSOLVE solvent improves penetration and contributes better leveling.

It readily dissolves resins, dyes, oils, and waxes, and is mild-colored and water-soluble, CELLOSOLVE *solvent is* available for immediate shipment.

As a brake fluid diluent . . . CELLOSOLVE solvent is an economical, medium-high boiling, stable diluent. Furthermore, it provides good low-temperature properties and is an excellent coupler for other brake fluid components.



PHYSICAL PROPERTIES OF "CELLOSOLVE" SOLVENT

Specific Gravity, 20/20°C.	0.9311
Boiling Point, °C. at 760 mm.	135.1
Dilution Ratio $\frac{\text{½ sec. Nitrocellulose}}{\text{Toluol}}$	4.9
Flash Point, °F (Cleveland Open Cup)	130

CELLOSOLVE solvent is miscible with water in all proportions.

If you need *other glycol-ethers be sure to check Carbide's complete list, including Methyl* CELLOSOLVE *and Butyl* CELLOSOLVE. *For more information, samples, and prices, call or write the Carbide office nearest you. Ask for the 1952 edition of the handy reference booklet, "The Physical Properties of Synthetic Organic Chemicals".*

The term "Cellosolve" is a registered trade-mark of Union Carbide and Carbon Corporation.

Volume 48
Number 1

Chemical Engineering Progress

JANUARY
1952

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Editor: F. J. Van Antwerpen ● **Publication Board:** W. I. Burt, Chairman; W. T. Nichols, Vice Chairman; C. R. DeLong, S. L. Tyler, T. H. Chilton ● **Publication Committee:** W. T. Nichols, Chairman; W. C. Edmister, A. S. Foust, W. E. Lobo, R. L. Pigford, E. L. Piret, F. J. Van Antwerpen.

Published monthly by American Institute of Chemical Engineers, at 15 North Seventh Street, Philadelphia 6, Pennsylvania. Editorial and Advertising Offices, 120 East 41st Street, New York 17, N. Y. Communications should be sent to the Editor. Statements and opinions in *Chemical Engineering Progress* are those of the contributors, and the American Institute of Chemical Engineers assumes no responsibility for them. Subscriptions: U. S. and possessions, $6.00; Canada, $6.50; Pan-American Union, $7.50; Other Foreign, $8.00. Single copies of *Chemical Engineering Progress* older than one year cost $1.00 a copy; others are 75 cents. Entered as second class matter December 9, 1946, at the Post Office at Philadelphia, Pennsylvania, under the Act of August 24, 1912. Copyright 1952 by American Institute of Chemical Engineers. Member of Audit Bureau of Circulations. *Chemical Engineering Progress* is indexed regularly by Engineering Index, Incorporated.

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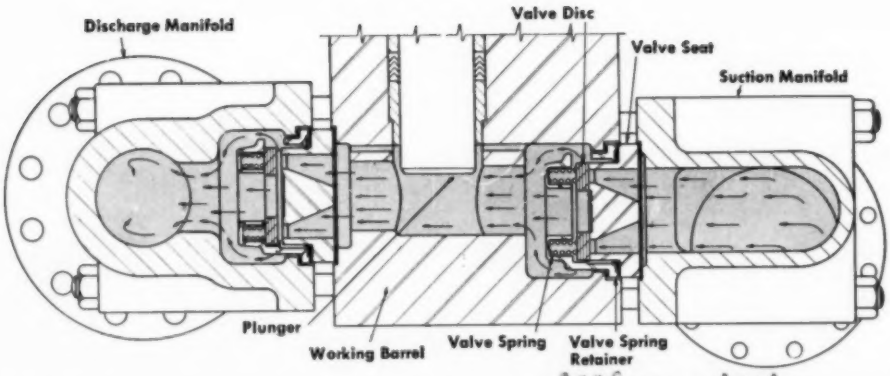
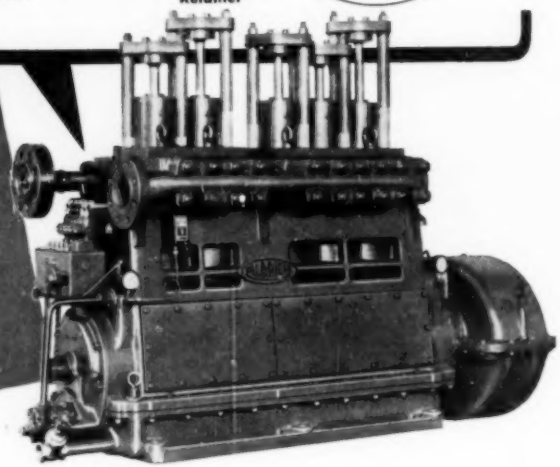


ENGINEERS: Check these points of Aldrich Direct Flow Design



Aldrich engineers eliminated two right-angle turns in the fluid-end. Now, liquid passes from suction to discharge manifold in a *straight line.* That gave the Direct Flow Pump its name, and set up a whole new concept of pumps, pumping, and pump maintenance. It all adds up as follows:

☐ **Increased operating speeds**—you get whatever volume and pressure you need *from a smaller, lighter, more compact pump.*

☐ **Sectionalized construction**—parts can be replaced at a fraction of the cost of a new fluid-end; also, parts can be made of stainless, bronze, Monel or other special materials—extremely important for corrosive fluid service.

☐ **Maintenance made easier**—no more tapered bores in the working barrel. Manifolds are *not* taken off but slide out on studs—affording room to *lift out* valves as complete units. Packing is easily renewed—note accessibility of stuffing boxes.

☐ **Interchangeable wearing parts**—available among 3, 5, 7 and 9 plunger pumps of same stroke size. This minimizes spare parts costs and inventories.

☐ **Changeable plunger sizes**—in many cases it is only necessary to add new plungers, glands, throat bushings and packing *to the same fluid-end.*

☐ **Drive direct**—by connection to synchronous engine type motor or internal combustion engine; also with integral speed reducer or V-belts.

Contact your Aldrich Representative . . . or write to us direct for complete details on 3", 5" or 6" stroke units.

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The newly developed Beckman Model N pH Meter not only meets all these requirements, but also many more. Here are the highlights. Check them over. *Never before have unique advantages like these been combined into a single pH instrument!*

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- Accuracy to better than 0.05 pH.
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- All-metal case—cast aluminum with baked enamel finish to resist wear and corrosion.
- Splash-proof design—fully desiccated internally.
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- Light weight—less than 8 lbs., complete.
- Small, compact—only 4" x 6" x 9½" overall.
- Equipped with the new Beckman Red Label Glass Electrode—virtually unbreakable, covers almost the entire pH range, usable from freezing to boiling.
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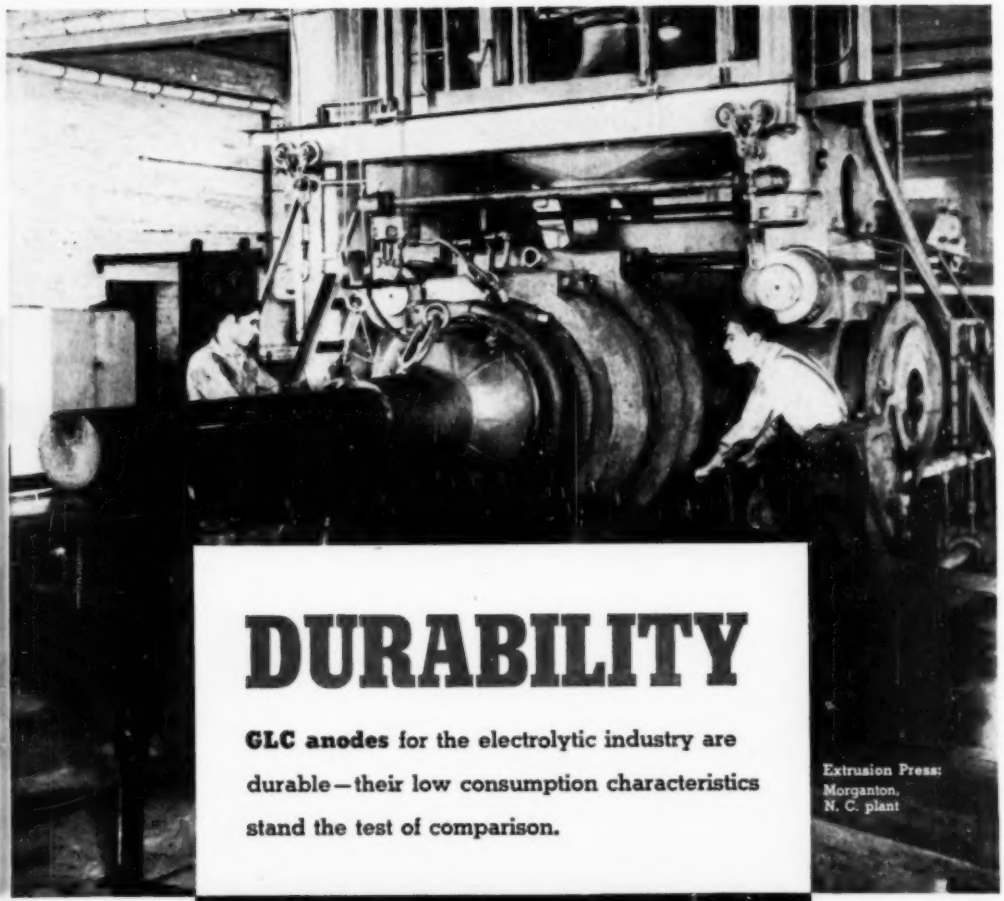
make the Beckman Model N a noteworthy advancement. The following features are typical . . .

ELECTRODE SUPPORT ROTATES alongside case for maximum convenience in carrying. Instrument can be used in either horizontal position (shown at left) or vertical position (above)—whichever is handier.

CONVENIENT CONTROLS not only centralize all operating functions, but also permit checking amplifier circuits and battery condition without opening case or disturbing battery connections.

RUGGED, COMPACT DESIGN withstands rough field and plant service with negligible maintenance. Solid cast-aluminum case is strong, yet light in weight. Beckman Glass Electrode is virtually unbreakable!

There are many other important features designed into the Model N. Be sure to get the *complete* story on this new Beckman development!



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GLC anodes for the electrolytic industry are durable—their low consumption characteristics stand the test of comparison.

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Merchant Coke Plant
Premium foundry and industrial coke. Coke co-products.

"Model" Grease Plant FOR CANADIAN OIL COMPANIES, LTD.

This lucite, scale model was the "blueprint" used by Fluor engineers to plan and construct the new modern lubricating oil and grease manufacturing plant for Canadian Oil Companies, Ltd., in Montreal. Being able to work out detailed designs in miniature, played a big part in the successful selection and location of all equipment to facilitate the natural flow of work through the plant with a significant saving in man hours. It is an example of the thoroughness with which Fluor tackles a job.

Over 300 varieties of specially engineered greases and lubricants packed in a multitude of sizes, from 3 ounce cans to 55 gallon drums, are manufactured, blended, packaged and stored in this efficient plant. It had to be built in a U-shape to incorporate the original plant which still houses much of the blending machinery. It had to be accessible to all forms of transportation by land or water. It had to provide storage facilities for raw grease stocks before processing and for interior storage of finished products. It had to be equipped with the latest automatic devices for heating, blending, sterilizing, conveying, packaging, handling, etc. and it had to be completed in the shortest time possible.

Fluor's experience with building and remodeling plants which use bulk materials for a variety of products, has long been established, but at Canadian Oil much of the machinery is Fluor designed—especially that used for handling materials. The flexibility of this equipment is almost human in its ability to switch from one type of product to another, from one type of container to another and from one type of carrier to another whether it be truck, box car, tank car, freighter or tanker, without loss of time for change-over.

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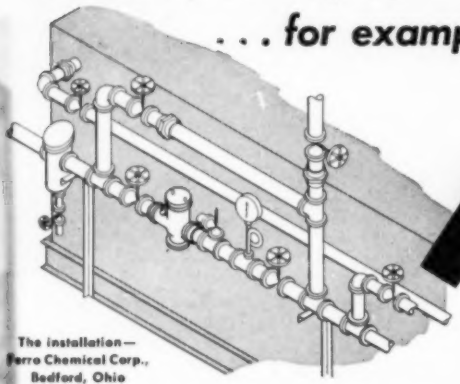
on Steam to Drying Ovens . . . for example



The installation—
Ferro Chemical Corp.,
Bedford, Ohio

PROBLEM: To maintain automatically, within close limits, uniform reduced steam pressure from supply line to battery of two drying ovens controlled by individual thermostatic valves.

WORKING CONDITIONS: Initial steam pressure of 70 psi to be reduced to 13 psi, and maintained without significant fluctuation whether one, both, or neither of the ovens is being operated.

SOLUTION TO PROBLEM: One No. 960 Crane Brass Pressure Regulator, properly selected for capacity required, and with adequate condensate drainage provided.

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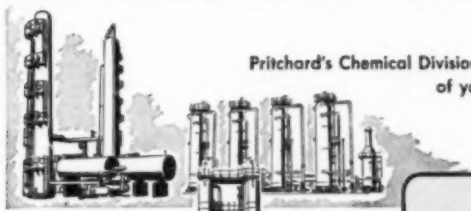
Today's supply of sulphur is extremely short, tomorrow's may be critical! Consult *now* with Pritchard's experienced engineers for specific recommendations on how a Pritchard Sulphur Recovery Plant can be put to work for you.



Pritchard's Chemical Division is eminently qualified to handle all elements of your project effectively and economically.
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PYREX brand Glass Pipe Features

EASY TO INSTALL. There are tricks to handling any material, but the tricks to handling PYREX brand Glass Pipe are quickly learned. It can be plumbed at your plant. Prefabrication to your requirements is unnecessary. One plant superintendent says, "PYREX piping can be easily installed. I cannot remember when we had any difficulty with installation or reinstallation after changes or repairs."

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It's corrosion and heat resistant, transparent, chemically stable, strong —and it can be plumbed in your plant.

The production manager of a well-known chemical plant reports: "Besides our problem of corrosion, the necessity of maintaining color standards for our products has made glass the ideal piping material in some of our processes. We have used glass pipe in this plant for many years and couldn't do without it."

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NOW STRONGER THAN EVER... The new PYREX "Double-Tough" Glass Pipe makes breakage even more unlikely. It is made from heavy-wall machine-drawn tubing. A new heat-treating process doubles the strength of the ends of straight lengths and of all standard fittings except U-bends.

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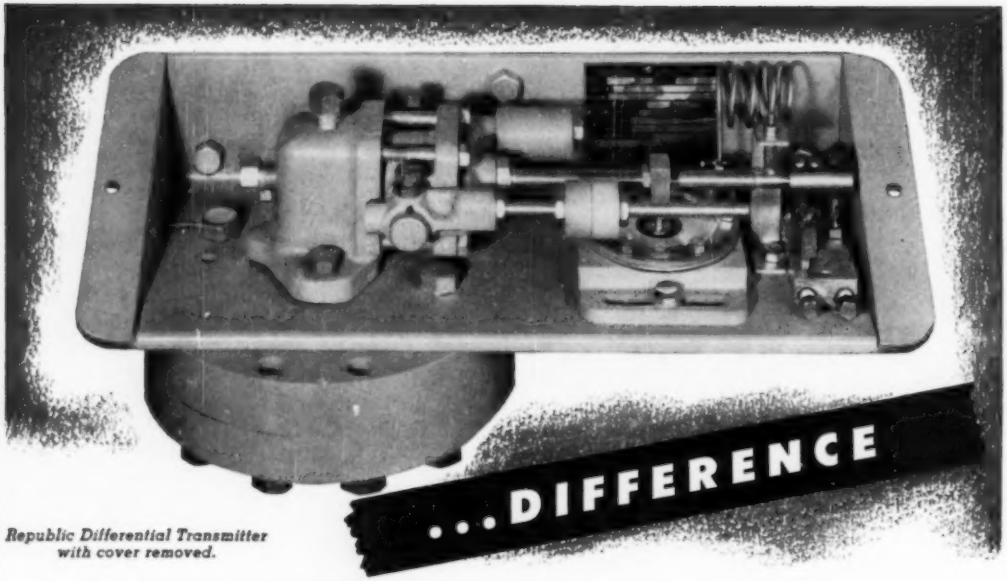

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Spells *PLUS* PERFORMANCE

The Republic Pneumatic Transmitter combines machine ruggedness with instrument precision to provide matchless performance in measuring flow, level, pressure or density of a wide variety fluids. By any or all of the following points, the Republic challenges comparison:

ACCURACY of the Republic force-balance principle is higher than can be consistently secured and maintained with any other method. 1/2 of 1% guaranteed.

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CHANGES IN LINE PRESSURE—Republic differential transmitters are not affected by variations in line pressure. A patented and exclusive simple adjustment assures this protection.

SENSITIVITY—Due to the negligible motions required for complete operation of all parts, for a full scale change, no appreciable hysteresis results from reversal of direction of measurement change.

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LEVELING—Since all parts are balanced, and no liquid is used for calibration, Republic transmitters need not be leveled exactly, and may be adjusted for installation in any position.

FOR TWELVE YEARS Republic Pneumatic Transmitters have delivered unmatched performance in every type of installation. Complete details of design and operation, plus numerous application suggestions are combined in Data Book, 1002. Send for your copy, today.

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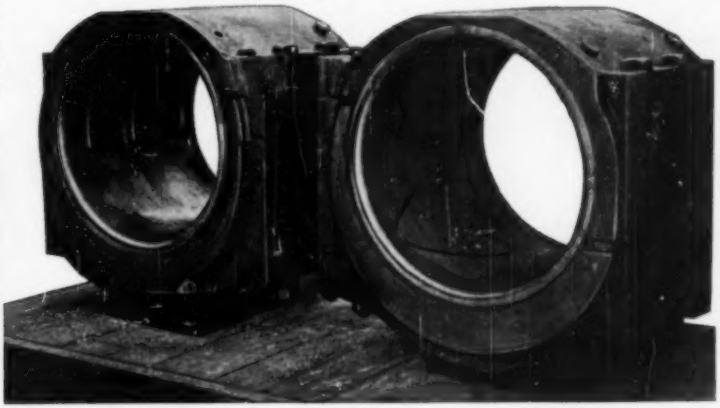
2240 Diversey Parkway, Chicago 47, Illinois

THIS PROPANE-BUTANE PUMP GEAR is cast in Olds 5% nickel bronze to assure excellent wearing qualities, since oil and grease fail to lubricate when in contact with such strong solvents as propane or butane. These pump gears (1¾" to 2½" O.D.) and sleeve bushings, of Olds high leaded nickel bronze, are used by Smith Precision Products Co., South Pasadena, Calif.

ON THESE SURFACES OF OLDS BEARING BRONZE ... a 19" journal, with .045" clearance, turned at 20½ R.P.M. for almost 9 years in a 4-roll calendar mill used in processing cord and rubber fabric for automobile tires.



NICKEL ALLOYED BRONZES

Resist Wear Under Severe Operating Conditions

These large bearings served continuously for nearly nine years at temperatures ranging from 80 to 120° F.

They are made of a high lead nickel-tin bronze, trade-named Olds Bearing Bronze, developed some 15 years ago by the Olds Alloy Company of South Gate, California.

Containing about 18% lead, 5% nickel, 5% tin and 10% zinc (balance copper), this wear-resistant alloy was approved by a leading aircraft manufacturer, early in World War II, for friction bearings operating without galling, under conditions of little or no lubrication.

Although high lead content in bronze alloys improves bearing properties, it lowers strength. However, an adequate nickel content provides age-hardening response which increases both tensile and compressive strength.

Furthermore, nickel tends to diffuse lead in the alloy, refines the grain, and increases resistance to corrosion and erosion.

At the present time, the bulk of the nickel produced is being diverted to defense. Through application to appropriate authorities, nickel is obtainable for the production of nickel alloyed bronzes for many end uses in defense and defense supporting industries.

If interested, we shall be glad to put you in touch with the foundry equipped to quote on your requirements.

ONLY ONE SET OF REPLACEMENTS IN 13 YEARS. That's how Olds Bearing Bronze economizes in frame bushings and thrust rings on mullers at the Pacific Hard Rubber Division of Stauffer Chemical Co., in Los Angeles. The two bushings shown with the steel shaft, from a muller, are typical of nickel-alloyed bronze parts that minimize galling and heatings despite the abrasive material handled in battery case manufacture.

INCO

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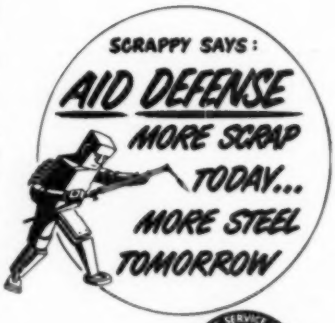
Get in touch with your local scrap dealer and write for the free booklet, "Top Management: Your Program for Emergency Scrap Recovery" to Advertising Council, 25 W. 45th St., New York 19, N. Y.



NON-FERROUS SCRAP IS NEEDED, TOO!

This advertisement is a contribution, in the national interest, by

CHEMICAL ENGINEERING PROGRESS

An important message for users of filter aids and mineral fillers:

JM

Johns-Manville Announces a 40% increase in Celite* production

AT A TIME when many vital materials are in short supply, Johns-Manville is pleased to announce that the culmination of two-and-one-half years of planning, designing and construction has resulted in a 40% increase in the production of its diatomite filter aids and mineral fillers.

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For further information about Celite and its availability for your process, write Johns-Manville, Box 290, New York 16, N. Y.

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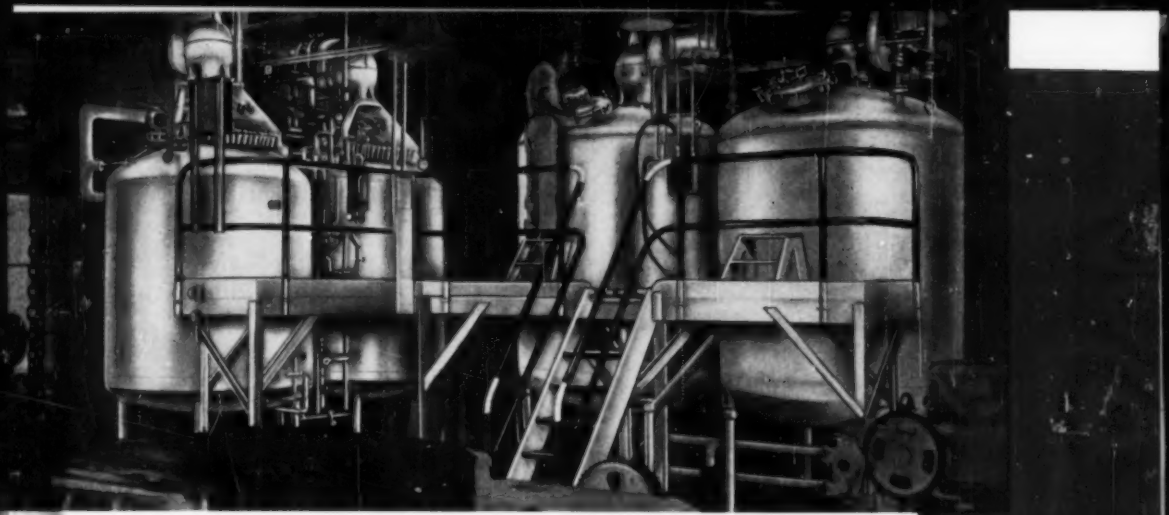

USERS, who have tested this new glass, find that it is *at least three times more resistant* to alkaline solutions than any Pfaudler glass formerly available.

How new Pfaudler *ALKALI-RESISTING* Glass can *save you time and money* all along the line

COMPARATIVE TESTS show that new Pfaudler alkali-acid-resisting glass (left) withstands buffered NaOH,pH 11.5 at 212° F. for 30 days with no noticeable change, while former high-quality Pfaudler glass (right) is severely etched under the same conditions.

WHY the chemical process industries prefer glass-lined equipment:

1. Pfaudler glass, backed by steel, is *one of the most durable materials of construction.*
2. Resistance to all acids (except hydrofluoric)—now combined with resistance to alkaline action for even greater flexibility and service life.
3. Product purity is improved by elimination of metallic contamination.
4. Ease of cleaning and sterilizing protects product quality, saves time and labor costs.
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Pfaudler glass backed by steel—*one of the most durable materials of construction* known to man—is now better, more flexible, and more economical to use than ever before!

ACID-RESISTING, TOO!

The new Pfaudler glass was specially developed to give *longer life* to glass-lined equipment where alkaline reactions are encountered, but *without any reduction whatsoever in its acid-resisting properties.* It promises to solve many chemical processing problems in the pH range from 9 to 12, which, until now, have been unusually severe on glass-lined equipment.

ADDED FLEXIBILITY!

Now, for the first time, the new Pfaudler glass makes it possible for you to go from acid to alkaline solutions in the same vessel. And the easy-cleaning features of Pfaudler glass-lined equipment allow you to make the change in minimum time.

HOW YOU SAVE . . .

This new flexibility means that you need only one vessel where dissimilar operations formerly required two. What's more, you can standardize on a single type of unit and narrow down on spare parts. You'll need fewer structures and be able to save space, too. And use of the new glass may even eliminate many of your valve, piping, pumping and gasketing problems.

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GET ALL THE FACTS! Send the coupon today for full details on this amazing alkali-resisting, acid-resisting glass.

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OPINION AND COMMENT

A CURRENT PROBLEM FOR CHEMICAL ENGINEERS

THE new year is with us with its new problems and many of the old ones which are only partially solved. The responsibility the chemical engineer takes in industry, and the chemical industry in particular, will take on increased importance during the year and I am sure he will be up to the job.

The chemical engineer of today is not primarily a design engineer of equipment or a process, as is stressed very greatly, and rightly so, during his college education. He has become a part of management and is called upon to perform practically every duty that management is called upon to do. I find in our company alone, when going through the organization chart, that we have chemical engineers as shift foremen and general foremen both in production and maintenance; technical men in the laboratory, on shift work following processes and making suggestions which will increase yields and lower maintenance and production costs; shift superintendents; technical superintendents; production managers; and plant managers. One might say that those are the jobs the chemical engineers were trained to do. But let me go on. Chemical engineers are in charge of maintenance for a whole plant; they are plant engineers, safety engineers, and are responsible for handling industrial relations calling for negotiations with the unions representing the hourly employees. Chemical engineers are in a majority in our development laboratories and in sales service laboratories. In sales they have most of the responsibilities including those of sales managers, for both national and international operations, sales representatives, advertising, and customer technical service. Finally, there are chemical engineers who are officers of the company in charge of research, development, sales engineering, and production.

We all know many who are presidents of their companies and doing outstanding jobs.

One may say, what does this all add up to? To me it means that chemical engineers not only have the technical responsibility of the chemical industry, but they also have sales, engineering and construction, financial, and executive responsibility.

As we all know, the chemical industry has been profitable to many groups, not only to the employees but also to suppliers of materials and equipment, to the stockholders, and to the government through tax revenues. One of the great factors in its success has been the industry's foresight in providing large sums of money for research and development. It has been pointed out in print, and by word of mouth by many, that in the past few years some discoveries of the research laboratory are lying on the shelf owing to a lack of capital to carry on the further development of the discovery and to uncover sales possibilities. Further, if sales potential is proved, there is difficulty in financing the final design and constructing the plant to produce the new product.

Why the lack of "risk" capital? When a survey is made for a new process, the sales possibilities (which depend a great deal on the selling cost of the final product, and in turn on the total cost of plant) are such that we find that the margin of profit, if there is any, "after taxes" is very small. Investors, or stockholders, then become unwilling to take a chance with their money, or management is not willing to risk retained earnings.

It therefore behooves the chemical engineers who have to develop process designs, construct plants, and sell finished products, to scrutinize each step as they progress, and only to make recommendations which will assure a profitable venture.

The problem today is much more difficult than in the "good old days" owing to the high corporate and excess profits taxes which confront our entire economy.

It can clearly be seen that management and chemical engineers will have to make every effort carefully to study every phase of their business and take all possible steps to lower costs whether it is yield, labor, maintenance, overhead or sales. This, of course, is what makes your job interesting and when you have succeeded in bringing about some improvement, it gives a great sense of satisfaction of a job well done.

WILLIAM I. BURT,
President, A.I.Ch.E.

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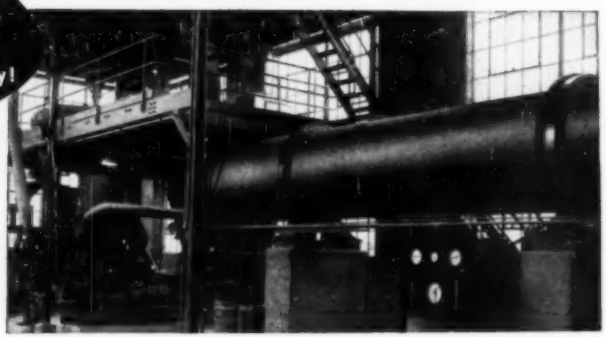

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Drying cost per ton	3.72

(space required, 1500 sq. ft.)

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YEARLY SAVINGS of LOUISVILLE DRYER in OPERATING COSTS ALONE $14,850

Other General American Equipment:
Turbo-Mixers, Evaporators, Thickeners, Dewaterers, Dryers, Towers, Tanks, Bins, Pressure Vessels

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Safety

ENGINEERING IN THE CHEMICAL INDUSTRY

By F. A. VAN ATTA

National Safety Council, Chicago, Illinois

With this issue we conclude the series on Safety under the general theme — Safeguarding What You Have — Here F. A. Van Atta examines the historical development of industrial accident prevention . . . George Armistead follows with an account of the chemical engineer's concern with safety because of the expansion of the chemical industries . . . James Duggan discusses the methods of organizing protection from dangerous and hazardous operations in a chemical plant . . . Our theme — Safeguarding What You Have — will be continued next month when we start a series of articles on plant maintenance . . .

IN order to understand the current position of any subject I feel it necessary to examine the historical development. It is particularly easy to follow the historical development of the safety engineer and safety engineering as a profession since it is only five decades since the first modest organized interest in industrial safety matters.

There were some notable exceptions to this. The founders of the Du Pont organization apparently felt from the beginning a definite paternalistic interest in their employees. As part of this responsibility, they stressed accident prevention beginning with the founding of the company. The care of injured workmen has also been accepted as a corporate responsibility of Du Pont about which there was no more question than about the responsibility of the management to the stockholders.

United States Steel Corporation also formed a central safety committee in 1906, just five years after its formation. The staff man responsible for this central safety committee was described as a former plant superintendent, long known for his interest in safety devices and employee welfare. We could still look further and do worse in picking a man to head a company's safety activities. By 1910 the United States Steel Corporation was paying voluntary workmen's compensation, at rates which were fixed and published, amounting to one million dollars per year. The maximum which they ever paid in compensation judgments was $52,000 a year.

I stress this point because there is a common theory that safety activity was forced on business by workmen's compensation legislation, which was in turn forced by the activities of organized labor and by public opinion. Those who hold to the idea that safety activity was originally forced by legislation, I observe, are inclined to think it still forced by legislation. This leads to quite a different concept of the proper activities of the safety engineer than that arrived at from thinking safety activities were essentially voluntary and are still essentially voluntary.

One can set up a good argument for the other side of this picture. It is still true that at the time of the enactment of the first Compensation Law in 1911 in New Jersey, one fifth of the litigation in the State Court was concerned with liability for damages as a result of industrial injuries.

The conditions were unquestionably bad. In 1906, the year of the "Pittsburgh Survey," there were 526 industrial fatalities in Allegheny County, Pennsylvania. A train man had one chance in 127 of death by accident in any given year. There was also plenty of outraged public opinion. I quote briefly from Crystal Eastman, secretary of the New York Commission on Employers Liability and Causes of Industrial Accidents:

> When I read in the bulletin of the New York Department of Labor, among particulars of fatal accidents in 1908 such records as this: 'Helper, flooring factory, age 18, clothing caught by set screws in shafting; both arms and legs torn off; death ensued in five hours,' my spirit revolts against all this benevolent talk about workingmen's insurance and compensation. . . . Who wants to talk about 'three years' wages to the widow,' and . . . . What we want is to put somebody in jail.

A Failing of Democracy

This is the sort of "hoorah" which goes on in a democracy when a great issue is under discussion, but it should never blind us to the fact that, in spite

F. A. Van Atta, director of industrial hygiene, National Safety Council, Chicago, Ill., since 1949, has as an avocation the designing and operating of two small chemical plants. Before going to the National Safety Council in 1942 as industrial hygienist, he held the title of industrial hygienist with the Illinois State Department of Labor from 1939 to 1942. Mr. Van Atta holds a Ph.D. degree from Northwestern University and has served as a graduate assistant at that university and at the University of Oregon. He was an instructor at Armour Institute of Technology from 1935 to 1939. He is a member of several technical associations.

of our traditional willingness to try, we probably have yet to legislate the first man moral. At the best we slightly inhibit the amoral members of society if most of us are in favor of a specific line of conduct.

In 1910, as at the present time, there were compelling reasons for industrial accident prevention. I expect they were recognized by all business executives, although they were probably assigned varying importance. The Du Pont executives seem to have been impressed by the humanitarian aspect. They had a feeling of responsibility for the men who worked for them and for the families of those men. I feel sure that the operations of the company had not grown to any substantial size before they also realized that industrial accidents and industrial injuries were a drain on the company's finances. This was certainly more obvious in a powder plant than in most other business.

There is also the legal responsibility. This is probably more important now than in 1900. In spite of theoretical unlimited liability under common law, it was actually quite difficult for workmen to obtain any substantial compensation for injury. Every company which put into effect a voluntary compensation plan substantially increased its direct expense for this purpose. One advantage of the law to the employer was that it defined his liability.

Safety's Role Not Sufficiently Understood

The role of the safety engineer in industry has not been well formalized nor have his responsibilities been well defined. This is partly because industrial safety has been strictly an industrial development. The duties and responsibilities have varied from plant to plant in accordance with the ideas of the plant management, but probably even more because industrial safety has not been recognized by colleges and universities, and no appreciable amount of academic thought or time has been given to formalization.

DeBlois in 1926 said that safety engineering had graduated from the movement stage to something more rational and standardized. What he really meant was that most of the reformers had transferred their attention to something else and left the industry to its own devices. It was not until 20 years later that there was any semblance of formal training for safety engineers. Safety engineering still has not become sufficiently standardized to fit into the corporate organization or into the academic scheme.

Safety engineers have standardized enough that we are perfectly certain that the fundamental causes of injuries are about the same and that they are pretty much independent of the type of industry involved. In every industry and home people continue to fall down, get caught in or between things, lift too much or lift in a strained way. Devices which are effective in preventing this in one place, are generally just as effective in another place.

This is all really a way of saying that the safety engineer has cut out a specialty for himself, and that he has classified and recognized a few of the unit operations in that specialty. This facet has been the result of statistical investigation, and much of the safety engineer's job is counting and classifying things. That does not, however, make him a statistician. Statistics is an important tool of the trade, but it is not the only tool and probably not the most important one.

Chemical Engineer to Appraise Hazards

It is a convenience, but not a necessity, for the safety man in a chemical plant to be a chemical engineer or chemist. He should have a general knowledge of the processes of his own plant. He should know enough to be able to follow new developments in order to appraise the hazards and the precautions which have been taken from the laboratory and pilot plant, and into the plant.

We regularly hear of injuries to plant personnel which are attributable to no other basic cause than the lack of foresight in the laboratory. It was not realized that exposure for a few hours on a laboratory scale may be quite harmless, while exposure to the same process for a full shift on a pilot plant or plant scale may be highly hazardous.

In the main the chemical industry is new enough to have been operating with safe methods from the beginning. Also a large number of the top executives in the chemical industry are chemical engineers with direct knowledge of what goes on in the plant and laboratories. As a result, it is usual to find precautions taken so that injuries resulting directly from chemicals are somewhat rare in the industry. No one in a chemical plant should ever forget that he is working on the brink of disaster at all times and that the price of safety is proper original design and continuous vigilance.

A major part of the job of the safety engineer is to keep everyone in the organization continually convinced and aware of this. A safety engineer will usually have a place on the staff rather than in the production organization and will work through committees. There should be an executive committee at the top level to set policy for over-all operation and, at least, an inspection committee among the workmen to look over the plant and make safety suggestions. Generally there will be one or more other committees between these groups. They will all serve a useful function in the technical sense, and not the least of their utility is the education which they will provide for the people serving on them. The personnel of such committees should shift from time to time to give everyone a chance to serve and to get the benefit of the education available.

Safety Equipment a Must

The safety department has little need for authority in the plant. It is just about as hard to enforce morality on a plant scale as it is by state law or by national law. It is the business of the employer and of the safety department to see that every man in the plant is provided with the necessary equipment for working both safely and conveniently. To this end the safety department should have a hand in planning and purchasing supplies and equipment.

After the employer has provided the necessary process safeguards and the personal protective equipment for the operators, the safety job has only begun. The rest of the job is education of the individual to operate properly within the limits of the process and equipment provided. This is especially well illustrated in French and Swiss experience where the processes of guarding are much more highly specialized than they are in this country and where also the accident rates are much higher than here.

Safety education amounts to detailed instructions for each job, and for the integration of safe procedures into these instructions.

Education and Safety

In a broader and eventually more important view it amounts to the education of individuals in such manner from childhood that they will be susceptible to this type of instruction. At the moment undoubtedly the most important thing that safety engineers in the chemical industry can do is to work toward the integration of safety and safe procedures into the curricula of the schools of chemistry and chemical engineering in the colleges and universities. This is something which is only beginning to be done within the last few years and even now only the smallest beginning has been made. It will not be the most time-consuming part of his job, and will probably be the part which shows the least immediate return, but it is still the most important thing which can be done for the industry in general.

Safety AND THE CHEMICAL ENGINEER

GEORGE ARMISTEAD, JR.

Chemical Engineer, Washington, D. C.

IN speaking about safety, it is appropriate first to define its meaning. To me, a chemical engineer looking with the broad view at plants handling chemical materials, I mean by safety, two things, the preservation of property, and the protection of people from accidents. I am concerned with the aspects of safety peculiar to operations in which the chemical engineer is engaged. I include in the chemical industries, petroleum refining, rubber processing, the gas industry and others employing chemical engineering.

Fig. 2.

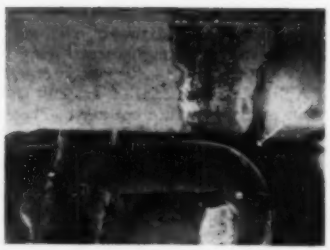

Fig. 3.

Two basic types of accidents are encountered. The first comprises the type occurring to workers in the course of their ordinary work and relations with one another, along lines more or less common to all industry. The second comprises accidents which are peculiar to our own industry and are primarily property damage accidents which may or may not affect workers.

Because of the great energy potentials possessed by many of our materials-in-process, we must assume that property accidents usually affect personnel, sometimes to a devastating extent. Accidents of these types include vessel and piping ruptures, ignition of escaping flammable materials, escape of toxic materials, firebox explosions, etc. In this latter type of accident many fatalities and serious injuries occur, plus a major economic waste from property destruction and lost productivity. Study of the causes of property damage accidents in our industries has shown one very im-

Fig. 1. ▲

Fig. 4. ▼

Wide World Photo

Fig. 5.

portant fact that we must all recognize. This is that they almost all originate in somebody's doing something wrong, even though knowledge of the right way is available. It is a statistical fact that almost none of our accidents is unforseeable in the light of present knowledge.

Accidents to personnel of the first type have been combated for many years. These mishaps are being lessened with improved engineering, better construction materials, safety guards on machinery, the holding of instruction classes of workers, movies, educational signs and placards, and continued effort to get the worker to think about avoiding accidents. We may say that all this effort is directed along two general lines, that is, (1) education and (2) engendering a definite safety consciousness in the employee. Similar approaches are usable in combating property damage accidents.

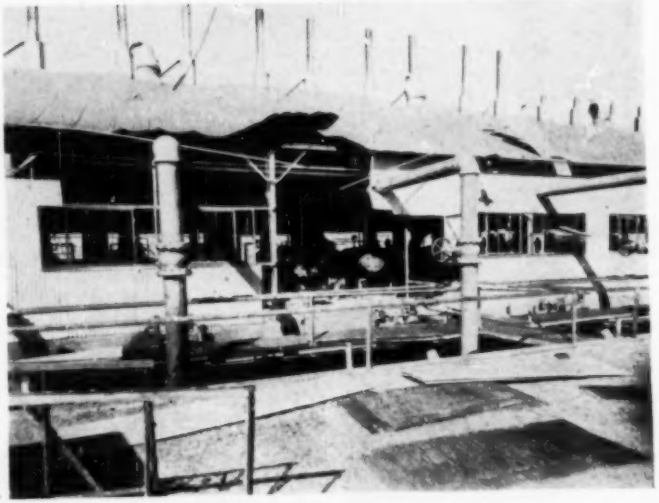

Fig. 6.

The chemical industries for the last fifty years have been expanding so greatly in size and changing so much in character, that in the minds of most, the approaches to safety have not been completely defined. As a consequence, there may not be today the clarity of purpose in approaching our own safety problems as exists for the personal accidents in other industries. Let no one minimize, however, the serious safety problems which have been met and mastered by the chemical industries.

With the advent, in 1913, of the thermal cracking process, the petroleum industry found itself saddled with a most perplexing safety problem. The question of maintaining a high pressure, direct-fired cracking vessel (and riveted at that) in one piece was great. One has only to recall fires and explosions which occurred on the old fired vessels at Whiting, Bayway, and Beaumont (and that the refiners were ignorant of many of the fundamentals with which they dealt), to wonder how men would ever be courageous enough to operate such hazardous equipment. Step by step, however, through research, engineering study, and exchange of experience, these hazards were overcome. The thermal cracking process, despite the high pressure and temperature and the flammable materials-in-process, became a relatively safe operation. These advances were duplicated in other lines. We may say from observation of the past, that we have *never* encountered a hazard which we could not satisfactorily overcome, within the petroleum refining

Fig. 7.

industry. One can recall, as an extreme, the aluminum chloride and hydrochloric acid operations of isomerization units during the last war. De-pite our inexperience and the vicious corrosive properties of these chemicals, we were able to handle the equipment with an almost perfect safety record. In view of this history, the premise is justified, namely, *that with the experience of the past as our tool, it is possible to approach complete elimination of the accidents which are peculiar to our industry.*

The complete safety program in any given plant includes many different divisions of safety activities and the experienced chemical engineer is usually the ideal type for its supervision. I have found that this work can be centralized in one man in a plant whom you might call a safety supervisor. This is an exacting job for him, and rightly so. He is in charge of protecting the lives of workers, the company's investment in property and the productivity of that investment, not to speak of the good name of the organization with the general public. He must be sufficiently capable to have the respect of operators when he talks to them about their equipment, and that of maintenance men when he talks about the sequence, scheduling, and manner of doing maintenance work. He must know enough about safety inspection to appreciate the searching-out duties and voluminous records which safety inspectors must keep, as well as to appraise such engineering problems as adequacy of static grounding, blowdown facilities, and organizational matters as the preparation and enforcement of engineering standards. Such responsibilities justify men of high caliber.

There is a tendency, when a typical chemical-handling accident occurs, for the people concerned to feel it an iso-

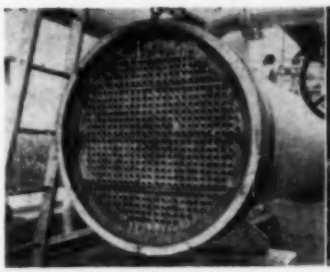

Fig. 8.

Fig. 9.

Wide World Photo

Fig. 10.

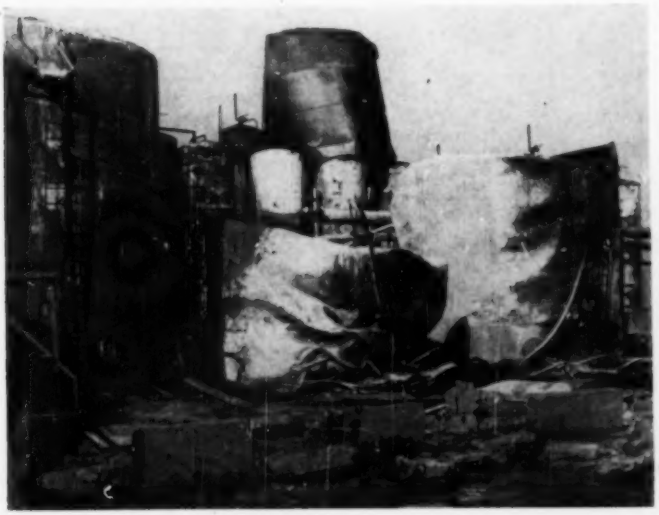

Fig. 11.

Fig. 12.

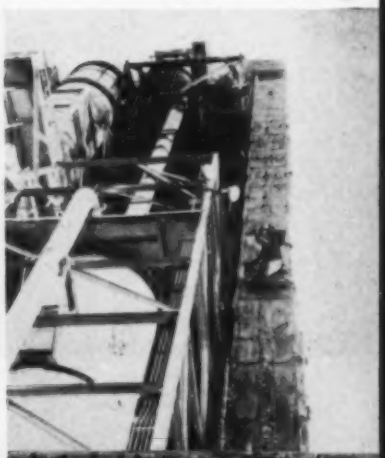

Fig. 13.

Fig. 14.

Fig. 15.

lated occurrence, a freak, which could not have been anticipated, and that the industry is thereby defenseless against such occurrences. Companies and individuals may come to think without an openminded and exhaustive survey of the field that *they* have complete knowledge of it, and that the precautions *they* take are the most effective that could be employed. These attitudes, even in a degree, are harmful.

As a matter of fact, accidents peculiar to the chemical industry follow well-defined types. We find accidents of the same type occurring again and again, even though to the subjects, they may be completely new. With the utilization of the past experience of the whole industry, extensive education, and follow-up, we can greatly reduce these accidents. We have only to make a concerted effort in this direction.

Below are examples of accidents in equipment typical of that which the chemical industries employ. To some of the victims the occurrence was a completely new thing; yet the accident occurs repeatedly in widely separated plants.

Fig. 1. Here is a butadiene fire which originated from a defect in a pump. Vapor blew out, flashed, and this fire ensued. While I do not advocate an absolute prohibition of touching any equipment while operating, the attempts to make adjustments on equipment during operation, including alterations to piping or even working on spares not in operation, have resulted in countless fires, explosions and fatalities. Note the operation of the water sprays on the storage tanks. This equipment did a good job on tanks in the background which were enveloped in flame.

Fig. 2. This shows a case of equipment failure. Here a cast iron tee was left in a 300-lb. liquid propane line. The line developed tension as it lay in the ground, and the tee parted. The whole near-by area was enveloped in the vaporizing propane, which soon flashed with highly destructive results. This is an emphatic illustration of the importance of proper materials.

Fig. 3. An illustration of equipment failure, this time due to localized corrosion. Here the materials were light hydrocarbons which soon flashed with destructive results. In some processes employing acids such as this alkylation unit, you have to use much care in operating, as well as diligence in metal inspection.

Fig. 4. An accident caused by an infrequently encountered effect in piping. This pipe line contained a mixture of air and hydrocarbon vapor left from its crude oil content. In the preparation for alterations and repairs, it was evidently ignited, and a high speed detonating combustion with a heavy shock wave developed. This is characteristic of combustion in long conduits, and the flame speeds are in the range of 250 ft./sec., many times that of ordinary combustion of flammable mixtures. Here about two and a half miles of pipe were destroyed. Note that the pipe appears to have been blasted by an explosive, and has come out of the ground at intervals. This occurred in Oklahoma.

Fig. 5. Another view of the pipe line explosion effect. This occurred in the pressure testing, prior to startup, of a 30-in. gas line in Pennsylvania. Note the sawtooth configuration of the pipe fragments. In this instance, 3,000 ft. of pipe was destroyed. In another occurrence, in 1939, more than 20 miles were destroyed in a single explosion. Here we have a relatively rare type of accident, but a survey of the field shows its presence, and yields information on prevention.

Fig. 6. Now a gas explosion in a compressor house without resultant fire. In the building damage was low. Some gas compression plant operators have extensive

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automatic and manual controls to expedite shutting-down operations and cutting ignition sources in case of breaks or major release of gas.

Fig. 7. Here, escaping gas in this pump house, containing a pit, ignited with extensive destruction. Escape of flammable gas from equipment must always be reckoned with, for this kind of destruction can, and does result.

Fig. 8. A case of vessel rupture from thermal expansion. This large heat exchanger had its inlet and outlet blocked on the tube side, and the tubes were substantially filled with water. It had no means of relief from pressure from the tube side. When steam was put on the shell side, the expansion of the tube side liquid raised sufficient pressure to blow off the channel end of the exchanger.

Fig. 9. A view of the channel on the ground below. This gives a graphic idea of the pressure generated by expanding liquid. . . . This sort of accident has occurred, in addition to this Gulf Coast location, in Kansas and in Indiana, to my knowledge.

Fig. 10. We come now to the exploding storage tank, either from the pressure generated from external heating or from ignition of flammable gas contents. This occurred in New Jersey. It was an asphalt cutback tank, I understand, and the bottom seam was the weakest.

Fig. 11. A dramatic view of the end of the road for a tank in Texas which blew up in precisely the same manner as the tank in Fig. 10. The tank rests upside down on the two drums in the center top. Its base remains in the left foreground. Here again is precise repetition.

Recently another tank exploded which involved only the roof and upper shell, caused by mixing hot oil into the water layer. The damage to surrounding tanks and equipment was very high.

Fig. 12. Illustrations of the chimney or stack effect, a naturally induced draft which can be highly destructive. In high equipment or equipment with vertical passages, it must be expected. In this view, the fire occurred on a freight elevator shaft, not extraordinarily destructive, but illustrative of the effect. Here, incidentally, is shown the hazard from asphalt coated sheet metal on such a high vertical structure. This has also occurred repeatedly.

Fig. 13. In this catalytic cracking kiln, of which the outside of one section is shown, a natural draft started, fed at least partly from air leaks in the walls, and overheated the internals. Some suggestion of the overheating is given by the distorted tube sheets.

Fig. 14. This shows the condition of the internals of the kiln. It had become a blast furnace from the naturally induced draft burning the carbon-impregnated catalyst. There were at least three instances of this accident.

Fig. 15. This picture shows the result of a chimney effect that initiated combustion in a Cottrell precipitator on a carbon black plant, following cooling water failure. Note the failure of the electrodes. The wrought iron frame in the center was actually fused in spots.

Figs. 16 & 17. An example of the exploding pressure vessel when subjected to fire. There seems to be some impression that safety valves if big enough will protect a vessel that is enveloped in flame during a fire. We must understand that this protection is only partial. A dry portion of a vessel can get overheated and fail even though the relief valve is functioning, as this picture shows. These failures are particularly dangerous to people. Note how this vessel opens up into flat plate. Fig. 17 is another pressure vessel that has opened up under fire conditions.

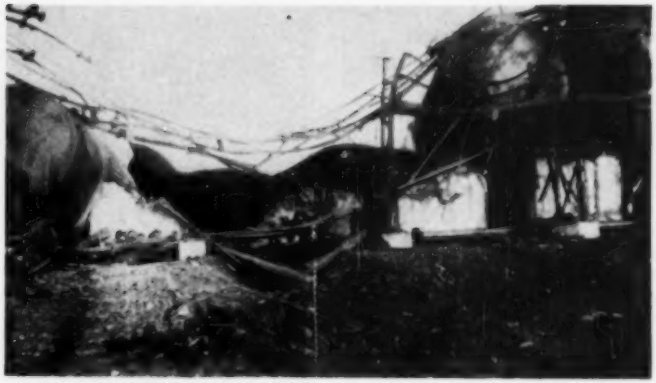

Fig. 16.

Fig. 18. An example of a vessel rupture caused from flame envelopment. The fire came from the big line shown at the right of the photo, and originated from a drain nipple failure (which by the way, has an unsavory reputation of its own). Parts of the vessel shown in the center beyond the steelwork were thrown hundreds of feet.

Fig. 19. Fragments from exploded pressure vessels in a New York fire which blew through the air several hundred feet and killed several bystanders. The history of pressure vessel explosions has been consistent and definite. This same thing has happened in many other places.

I could cite other repetitions of accident types. I can recall many instances in recent years where destructive accidents, including fatalities occurred, which obviously could have been avoided by the most elementary education of foremen and workers, accompanied by consistent safety policies.

Specifically, I am advocating a thorough education of workers in our industry on the general and specific hazards with which they deal. This should be accompanied by a continuous program to make them conscious of the safety requirements of the plant in which they work. This includes not only education along fundamental lines, but specific consideration of various plant

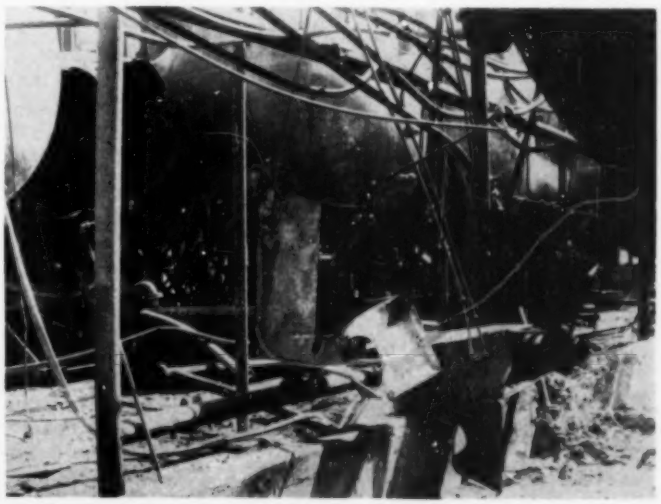

Fig. 17.

units, outlining of procedures to meet unusual or emergency conditions, the standardization of maintenance practices, the maximum cooperation between operating, maintenance, and safety inspection forces, and other phases. Such programs require ingenuity on the part of the coordinator of safety activities. He must make educational work attractive and interesting. The use of published material, movies, plant demonstrations and the like are all important phases. Above all, both plant and company management must be sympathetic with the safety program.

Regarding the secondary measures in connection with fire prevention and protection, since we cannot presently forecast complete freedom from fires, we still have to protect our structures and make them as resistant to fire as possible. We must have adequately trained fire departments and the facilities for combating fires, and we must have first-aid facilities for the accommodation of injured workers. These provisions keep little accidents from becoming big ones. However, there is sometimes a tendency for fire protection activities, the giving of first aid, disaster organization, and the like to be confused with preventive measures. These things have to do with handling an accident *after it has occurred*. Let no one confuse them with *prevention*. They are the things we have to do because we failed in our safety efforts.

In summary, I wish to emphasize four points. These are:

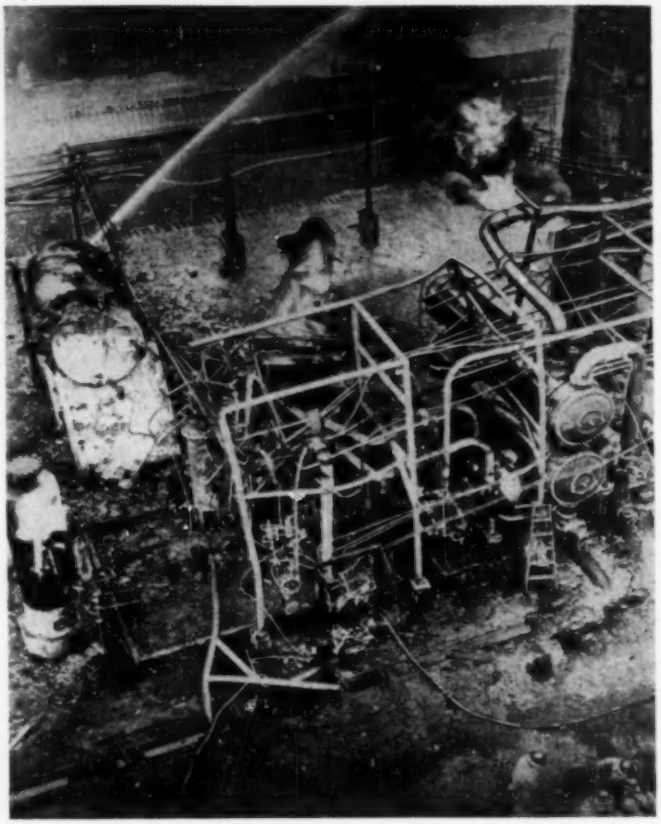

Fig. 18.

Fig. 19.

1. The objective of safety efforts within the chemical industries must be primarily *accident prevention*. We must not confuse the necessity for customary remedial efforts with the actual accident prevention.

2. We need continued education of workers from top to bottom in our industry to give them the best means of combating hazards. To do this, we need a concerted effort to utilize past experience.

3. We need a constantly maintained safety consciousness among all our workers.

4. Management must consider safety as one generic whole and must centralize responsibility for it in some effective fashion, utilizing capable people.

The chemical engineer must occupy the front line in the campaign for safety, and he must accept that responsibility as an indivisible part of his professional obligation. His endeavors will be effective in proportion to his acceptance of the possibility of continuous improvement in the accident record, and the rejection of defeatism and the reliance on remedies.

Organizing

FIRE AND EXPLOSION PROTECTION

JAMES J. DUGGAN

Carbide and Carbon Chemicals Company

South Charleston, West Virginia

COMPLETING an uneventful flight sometime ago, a huge four-engine airliner gracefully touched its wheels at Shannon Airport in Ireland. During the landing run, the pilot called for "flaps up," a routine function of the copilot. Seconds later, a $1,500,000 airplane was a pile of junk. The copilot, familiar with the control locations of another type of plane, inadvertently operated the landing gear lever, retracting the wheels and dropping the moving plane to the pavement.

Rubber production was decreased 5,000,000 lbs. monthly when a mechanic used a cap screw instead of a stud bolt to hold a packing gland in place on a butadiene pump. The vapors traveled 185 ft. to a source of ignition; fire burned for 6 hrs., loss in the millions.

A small drain valve on the bottom of a liquefied petroleum gas storage tank became inoperative due to lack of maintenance and use. When the operator could not open it, he secured a long-handled wrench. Result: fracture in the threads of the nipple, releasing uncontrolled millions of cubic feet of flammable vapor; ignition; extensive damage to adjacent processing equipment; loss in the millions.

A pot head failure on an incoming power line—failure of automatic switching equipment. Result: complete plant shutdown; loss of all utilities, including the all-important water supply. Luckily, there was no ignition of the flammable vapors released, but an extremely hazardous condition was created throughout the processing areas resulting in days of lost production.

In other words, a hazardous operation can be anywhere.

The extent of the hazard depends on many factors, and perhaps we will attempt to define and correlate some of these factors.

First, we must determine what the hazard of the operation is. Is it chemical? Mechanical? Electrical? Fire? Or Human?

The word "hazardous" is defined by Webster as "Depending on chance or luck, dangerous or risky." If we are to take this definition literally, when we say we have a hazardous operation, then we admit that we are taking chances. If we admit the operation is risky, then we are likewise admitting that we have ignored the requirements of safe operation, or we are admitting that we do not have the "know how" to operate safely.

There is an old adage that a good electrician respects rather than fears electricity as a hazard. By the same token, I have heard the expression that one gallon of gasoline in a silk mill is far more dangerous than one hundred million gallons of gasoline in an oil refinery.

All this points to the primary question: "What is the hazard of the operation?"

If the chemical phase is not the hazard involved then it possibly becomes the contributing factor, because industries do have fires and explosions. Perhaps the hazardous phase of the operation is mechanical or electrical. If this is true, we have disregarded some basic requirement because there is sufficient mechanical "know how" to design, build and operate equipment with sufficient mechanical strength and characteristics to withstand successfully temperature, pressure, corrosive conditions, etc., involved in processes.

If the hazardous phase of the operation is due to the human element, then we lack "know how" some place along the line. Maybe the designer, the builder, the supervisor or the operator has been inadequately informed as to the limitations and characteristics of the compounds he manufactures or the equipment under his supervision. Invariably some one connected with the operation has the "know how." If this "know how" has not been passed along to the group that lives with it every day, or if the chemical engineer has not passed along the characteristics of the compound to the operating personnel, then we can expect fires, explosions, loss of human life and loss of production. The answer has been implied: Safe operation requires the cooperation of all, that each may pass on to the other his "know how." This means that group control, to act in an advisory capacity to the operating supervision, is necessary to establish safe maximum allowable limits.

Where such procedures are followed, it has been found that hazards are minimized regardless of the type of product handled. A good example is the building and operation of the atomic energy plant at Oak Ridge, Tenn. Physicists, design engineers and operating personnel worked closely and in complete cooperation on that project, one of the most hazardous ever conceived by man. By advanced study and cooperation of all connected with the process the potential hazards involved were so completely controlled that, in the history of the operation of the Oak Ridge plant, there has been no appreciable destruction of property. The injury frequency and severity rate place it below some of the other industrial operations which are classed as non-hazardous.

Some industries do have fires and explosions. It seems we cannot depend upon the design and operating "know how" to protect plant properties. It is necessary therefore to apply another requirement; the control of fires and explosions that occur.

Experience has taught that segregation is of paramount importance in order to prevent damage from explosions and the spread of fire to adjacent areas. Where adequate spacing between processing units and ignition sources is provided, a minimum of fire protection is required. Where processes and equipment are closely assembled, extensive damage is caused when fires occur, unless other protective means are used. This can be accomplished in several different ways:

1. By resistance construction—the exclusion, as far as possible, of combustible materials.
2. By the installation of automatic fire extinguishing or control systems, such as water sprays or total flooding carbon dioxide systems, that are designed to function in times of emergency.

Standards covering this phase of operation are just as adequate as the mechanical design standards.

After all these things have been done, a hazard may still exist, sometimes because of the inability of man to be two places at one time. This is overcome by adequate instrumentation and automatic controls which record such items as temperature and pressure and maintain operating conditions within certain limits.

Another phase of instrumentation is control under abnormal conditions. Safety valves are a good example. Some safety valves in use today are little better, as far as capacity is concerned, than a whistle. Some standard valves have less than 25 per cent of the capacity of the nozzle to which they are attached. They are token rather than functional and when an abnormal condition occurs which may involve an increase in pressure within a closed vessel, it is possible that there is only one item in the entire process that can alleviate excessive pressure—the safety valve. If it has insufficient capacity, it is of little or no value to the operation.

Again, after all these things have been done, there still may be hazards unless the equipment and devices are maintained adequately and continuously. Deterioration starts with any mechanical device the day that it is installed. Therefore, preventive maintenance procedures must be injected into our scheme of things. The useful operating life of mechanical equipment can be increased tenfold by operating such equipment within its mechanical limitations and by preventive maintenance methods which can and do retard deterioration.

Fortunately, there exist many devices, methods and techniques which are of very material assistance to us in our preventive maintenance programs.

Isotope and radio-tagged chemical compounds are finding use in processing technology. Their many uses include fundamental studies of complex chemical reactions, lubrication efficiency and motor wear, and corrosion control; in gauges to register the contents of inaccessible tanks, for locating the movement of bulk materials, to measure and control thicknesses of film coatings, sheet materials, etc.; radiographic examination of welding, foundry work, steel structure and other nontransparent materials for flaws and imperfections.

Nondestructive testing methods are being utilized through the use of instruments wherein metal thickness can be determined, corrosion rates established, etc., while the equipment remains in operation.

Low-temperature stress relief of welded metal members is now available wherein members can be stress-relieved in any location, eliminating the return of items to the manufacturer for heat treating.

How are all the requirements for control of hazards brought together? First, by an organization which brings together individuals who have extensive knowledge in their field and who have shown ability to cope with destructive forces. The first requirement of such a group should be experience; the second, knowledge of the hazards, and the third, technical training. These three are rarely found in one individual. More likely they are found in a group of six, or eight, or ten, but wherever they are, they should be brought together.

If you know your hazards, you will respect, not fear them.

Discussion

Mathew M. Braidech (Chairman of Symposium): Has anyone had any experience with the use of radioactive isotopes in atmospheric grounding for static elimination? Reports from the field, especially from the cotton industry, are that it is being tried out in the ginning processes where trouble has been experienced with so-called "fire-packed bales" or fires hidden within the bales. These result from friction burns caused by lint accumulation due to static. This occurs particularly in the high, dry areas of Texas. This radiation method of atmospheric grounding through ionization has been used in one experimental gin with some success.

F. A. Van Atta: Radioactive static eliminators work by alpha-particle bombardment good for about three to four inches from the source of static. If you can get a bar up as close as that to where your static is being generated, you can dissipate it.

The U. S. Radium Corp. is interested right now in developing a bar which would operate by beta-ray bombardment with high energy beta radiation and which would be active over considerably larger distances; however, it will probably be quite sensitive to any dust in the atmosphere. We've had some experience with these things, on a relatively small scale, particularly over the ink fountains in printing plants and in rubber plants where one gets considerable amounts of static and pretty destructive fires. Such eliminators have been quite successful. They are easily installed and not excessively expensive. They are not, however, entirely free from hazard to personnel and better get a pretty good radiation physicist to look the job over.

R. D. Sieg (Corn Products Refining Co., Argo, Ill.): Mr. Duggan, will you give the details of your method for checking safety valves while operating.

J. J. Duggan: Our installations require that a shut-off or stop valve, which is sealed open under normal operating conditions, be placed under each safety valve. Operating regulations require that the unit operator is the only individual who has the authority to break this seal and close the valve. Likewise, the mechanical inspector alone has the authority to seal the valve after it has been reopened by the operator. This arrangement permits safety valves to be removed, repaired and/or tested under normal continuous operating conditions or, of course, when the unit is down.

In some locations, particularly with large-size valves, we have installed a spool or what is called a filler flange between the shut-off valve and the safety valve with an outlet that permits the testing of the safety valve in place by closing the shut-off valve and applying nitrogen pressure to the valve to determine its setting. If repairs are necessary, the valve is then removed, immediately repaired and replaced. If not, it is immediately placed in operation and the shut-off valve sealed open by the mechanical inspector in the presence of the unit operator.

James J. Duggan, for 28 years with Carbide and Carbon Chemicals Co., a division of Union Carbide and Carbon Corp., is now superintendent, mechanical and fire safety. For the first eleven years of this association he was engaged in the field of construction, maintenance and operation. The past 17 years have been devoted to fire prevention and protection involving extensive fire research for the design and application of fire extinguishing and control techniques. He is the author and coauthor of several articles on fire prevention, heat-retardant paints and coatings, etc. He is a member of the Research Committee, President's Conference on Industrial Safety, member, executive committee and past general chairman, Chemical Section, National Safety Council, and National Fire Protection Association Technical Committees.

This type of installation applies to manufacturing equipment (unfired pressure vessels) only, and not to any type of steam boilers or steam generating equipment, in which case shut-off valves are not permitted.

Loren P. Scoville (Jefferson Chemical Co., Inc., New York, N. Y.): Mr. Duggan. I have seen many cases where safety valves would pop on test at 100 or 200 lbs. higher than the set pressure. We believe it to be absolutely essential to have regular tests and inspections on safety valves.

Furthermore, there are many other types of safety equipment used generally, such as liquid level alarms on the suctions to compressors. These pieces of equipment do not operate day by day and they tend to be forgotten by the maintenance crew. However, the failure of one can mean a serious fire.

J. J. Duggan: In all of our plants, as Dr. Braidech has said, pressure and atmospheric equipment and their appurtenances are on periodic schedule for retest and/or inspection. In the case of safety valves, this retest period is established by the service record of the particular device. All safety valves are tested and/or repaired at least once each year. Many that are in severe service are checked, tested and repaired, if necessary, as often as once each week. Every effort is made to maintain the safety valves in operable condition at all times. When a safety valve has been actuated, we reset and reseat the valve as soon as normal conditions have been established.

The periodic schedules on other types of instruments and control devices are handled in a similar manner. Such instruments as are used daily are not necessarily retested; however, they are checked at least once each year and a record as to their condition becomes a part of the general service record on the device. The connecting piping to the safety valves or control devices is an important part of the device itself. Care must be exercised in providing a sufficient capacity for the service intended in the original installation and thereafter when inspections are made piping, manual valves, etc., must receive the same attention as the device to which they are connected.

N. H. Walton, (Atlantic Refining Co., Philadelphia, Pa.): In Mr. Armistead's presentation, he had a picture of a compressor house where there had been a failure but no fire. What automatic shut-off devices or other means are used to effect that result?

George Armistead: The mention which I made of shut-off devices for compressors and the like had no particular connection with the lack of fire in the compressor house which I showed on the slide. It just happened that there was not a fire in this particular instance.

However, the company on whose properties this compressor explosion occurred does have two kinds of emergency shut-down provisions for compressors, which are very valuable from the safety standpoint. One is the ordinary high level type of alarm and shutoff which will shut the compressor down in case of a high liquid level in the suction drum. The other arrangement is the provision of numerous manual push-button stations located around the plant area where operators can shut down the compressors and the boiler house in case of any justifying circumstance, such as a gas line break or the like. It is sometimes of great importance to cut all fires and possible electrical ignition points in order to prevent a fire from the escape of gas. In all probability this system was used in the fire exhibited on the slide, although our records do not show that.

J. H. Nichols (St. Louis, Mo.): Mr. Duggan, how does the safety department cooperate with the maintenance department in your organization on inspecting metal pressure vessels, etc., on installation as well as later on?

J. J. Duggan: All types of inspections and tests are performed by the personnel of the mechanical division of the safety department in cooperation with the maintenance department in that the apparatus to be tested is usually prepared for test by the maintenance mechanics. The mechanical inspector is responsible for the application of the test pressure and medium, etc., and written reports indicate the results of the test. Our mechanical safety groups are part of the general safety department; however, the group serves basically as a mechanical engineering division and is composed of men with technical backgrounds or with long practical experience in the mechanical field.

J. H. Nichols: Is it only in special cases that extra attention is given to the amount of tension on bolts, etc.?

J. J. Duggan: No, that is not in every case. To clear that up—the maintenance department when it repairs a piece of heavy flanged and bolted assemblies, etc., calls in the mechanical inspector. It is the job of the mechanical inspector to supervise the uniformity of stress on each bolt, which has been predetermined by the engineering department.

Cecil Rose (Sheffield, Ala.): How do you go about grounding some of this equipment—pipe lines, and other vessels—to prevent danger from sparks?

H. L. Miner: I recall a static problem with a battery of long coating machines which occurred many years ago. The coating material was thinned with a highly flammable solvent. Solvent was evaporated in the machines to bring the solvent-air mixture in them above the upper limits of their explosive range to prevent an explosion should a static spark or discharge take place when the machines were started up. During the operation of the machines, which were steam-heated, the solvent vapors were condensed by circulating the vapor-air mixture over condensing coils, thus keeping the vapor-air mixture in the machines below the lower limits of the explosive range. However, when the machines were started up, possibly at times during their operation, and when they were stopped, the vapor-air mixture passed from the rich through the explosive range into the lean or vapor-free range or vice versa.

An electrical engineer was continually checking the machines to spot locations where static electricity was being generated or accumulating so that that part of the machine could be grounded or otherwise protected. Finally a heavy copper cable was run full length of each machine, and every part where static was being generated or accumulating was effectively grounded or bonded to the cable which in turn was effectively grounded or bonded at each end and in the middle to water piping, so that the breaking or loosening of a ground wire or even breaking of the main cable would not destroy the effectiveness of the machine-grounding system.

Previous to this, several severe flash fires and explosions had occurred, with injury to employees and extensive property damage. After the machines were effectively grounded, so that, first, the machines were thoroughly balanced, static charges could not discharge from one part or another, and second, static could not accumulate in sufficient amounts to become dangerous, no further fires or explosions were experienced. However, one morning when the manager was passing a machine he noted a loosened ground connection on one of the coating knives, and before the electrician could be reached to secure it a discharge took place and fire resulted, which emphasizes the importance of maintaining all ground connections in good condition.

M. M. Braidech: There are two principal points in preventing static: (1) to throw all equipment where static may be developed or accumulated into balance, which prevents the discharge from one point to another, and (2) then lead it off to a ground.

E. T. Neill (Dow Chemical Co., Freeport, Tex.): Mr. Armistead said that a safety valve on a pressure vessel is no guarantee against rupture during fire. He said there should be a sprinkler system or insulation for full protection

of pressure vessels of flammable materials.

George Armistead: Experience has repeatedly shown that relief valves set slightly above normal operating pressure are not complete protection. Either insulation or some kind of cooling spray, or both, are necessary to keep dry walls from getting overheated by enveloping flame and losing strength to the point of failure. The choice between insulation and cooling sprays depends upon circumstances. Sometimes the water supply and runoff problem is so difficult that insulation is indicated. Insulation is generally foolproof and relatively low cost, but you have to be sure that it is applied well enough to stay on in case of a near-by explosion or torch fire. If it falls off, the vessel is right back without protection again. Mr. Duggan has shown some cases on his slides where insulation stood up well, but there is also some rather bad history for insulation which I attribute mainly to the fact that its function as fire protection was not considered when its design was worked out. I have no doubt that you can set up insulation that will stand up ruggedly under fire conditions.

Then, of course, there is still another alternative. You can have a blowdown or dropout system. That is, you have either to keep dry pressure vessel walls cool or you have to release the pressure on the vessel. An intentionally operated blowdown facility is not always practical. If you have a lot of tanks of propane or butadiene or volatile material like that, it may be impractical to blow all that down somewhere, both from the quantity disposal standpoint and the problem in vaporization and resultant refrigeration in the dropout system. There are cases, however, where you can easily handle vaporizable materials by blowdown, particularly with the less volatile liquids and vapor. Furthermore, there are installations in the country where large volumes of propane are dropped out into emergency tankage vented to a stack in which only a partial pressure reduction takes place. Such a system can drop out the main body of flammable liquid and help to clear the vessel, but of course you have ultimately to vent vapor to get the pressure down. I should emphasize again that for protection of such vessels you have either to protect dry walls from getting overheated by enveloping flame, or you have to be able to reduce the pressure to where failure cannot occur. The relief valve does not serve these purposes.

E. T. Neill: In calculating the size of safety valves for fire protection I understand there are about seven different methods used, and some give sizes as much as eight times that of others. What method would you recommend?

J. J. Duggan: In determining the required capacity of safety valves, complete knowledge of the operating conditions which the device is to serve is the primary requirement. In some instances, such as air receivers, the capacity would be based on the pumping capacity of the compressor of which it is a part. For kettles, fired-type boilers, etc., the required capacity would be determined by the heat input from the heating coil in the tank, etc. In the case of protection against fire exposure, capacity of the safety devices would have to be based on the most severe condition to which the vessel would be subjected. In other words, it has been rather definitely established that an uninsulated or unprotected tank containing liquid when exposed to fire will absorb heat at the minimum rate of 20,000 B.t.u./(hr.)(sq.ft.) of the internal surface wetted by the contained liquid. In this case, the safety valve capacity would be based on that rate of heat input. It has likewise been rather definitely established that vessels protected by noncombustible insulation or by water sprays will, under maximum fire exposure conditions, absorb heat at the rate of only 6,000 B.t.u./(hr.)(sq.ft.). In this case, the safety devices could be based on that figure. Generally speaking, to prevent overpressure in the vessels, the devices must be based on pumping rates, expansion due to operating temperatures, or possible heat input, whichever is the higher, giving due consideration to the type of protection afforded and the service in which the vessel is used.

As Mr. Armistead has mentioned, the presence of a safety valve, regardless of capacity, is not always the answer to the safety of a vessel under abnormal conditions such as fire exposure, in which case water sprays, noncombustible insulation or blow-down lines should be used to supplement the safety devices.

E. T. Neill: I have come up against the problem of storing ethylene oxide in large quantities. I understand it is a hazardous fluid to store even in small quantities. Has anyone investigated and arrived at a safe method of storing it?

J. J. Duggan: Considerable experimental work has been done recently and within the next few months a new I.C.C. requirement will be issued. The Manufacturing Chemists' Association has a brochure on this requirement also.

The test data indicate that although ethylene oxide liquid is a stable compound under conditions of both shock and elevated temperatures, the vapor is unstable, has an automatic ignition temperature of 1040° F., and will decompose at that temperature in a pure state, resulting in explosion pressures, the ratio of which is approximately 16 to 1. As a comparison, the explosion pressure ratio of acetylene when detonated is in the range of 10 to 1; therefore, ethylene oxide vapor may be a greater hazard from an explosion standpoint than acetylene. Basically, the protection required for tanks and equipment containing ethylene oxide is noncombustible insulation or automatically actuated water sprays which will prevent the shell in contact with the vapor phase from reaching the ignition temperature of 1040° F.

Anonymous: In processing cutback asphalt the mixing is done by pumping out from a bottom connection and pumping to an overhead line in the top connection, which possibly (and we think so) results in static generation. We are interested in finding some way of guarding against fire from such a cause.

J. J. Duggan: Research and experience have definitely established that static electricity can be generated by the dissociation of particles; therefore, the act of circulating, such as you describe, as the pumping out of the bottom and into the top of the same container, will generate static and unless it can be dissipated as fast as it is generated may build up a charge in excess of 10,000 v. This is true with any liquid. Experience indicates that where tanks have been properly grounded according to the National Electrical Code, the act of circulating such as you describe or the pumping in over the top have caused generation of static so rapidly that charges have been built up in the contained liquid faster than could be dissipated by the tank shell, thereby creating a differential between the contained liquid and the tank shell which have been responsible for static sparks that have set off explosions. The answer is, do not pump in over the top. Filling or circulating lines should be extended to below the liquid surface, thus eliminating the possibility of dissociation of particles which is known to generate static.

George Armistead: Only about three weeks or a month ago we had a rupture of a tank from this very same cause, pumping in over the top with resultant generation of static electricity and the blowing off of the roof. Fortunately, no fatalities or injuries occurred. This is a continual cause of tank explosions, and the answer is, to pump material in at the bottom, under the liquid level.

(The articles on Safety in this issue and in the December, 1951 issue, were adapted from a Symposium on Safety held at the Kansas City meeting. M. M. Braidech was its chairman.)

PRODUCING FUEL OIL FROM COAL

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It has been shown previously both on a pilot plant and industrial scale that fuel oil can be produced by the liquid phase high-pressure hydrogenation of coal. Recent work by the Bureau of Mines has indicated that impregnation of catalysts on the coal surface greatly increases the activity of certain hydrogenation catalysts. This increased catalyst activity has been utilized to decrease the hydrogen pressure necessary for the conversion of coal to usable fuel oils. Yields equivalent to 3 bbl. of fuel oil and 3500 cu. ft. of hydrocarbon gas per ton of Rock Springs Wyoming coal are obtained in a continuous pilot plant operating at 1500 lb./sq.in.gage.

ONE of the methods of producing synthetic liquid fuels from coal is by direct hydrogenation. The usual procedure is, first, to convert the coal into an oil by hydrogenation and, in a second processing section, to hydrogenate this oil further and reduce its molecular weight in order to obtain gasoline and other specification fuels. The first step, or so-called liquefaction of coal, in which it is partially converted to an oil, is the more difficult and expensive portion of the hydrogenation process. The laboratory and pilot-plant investigations at the Bruceton laboratories of the Bureau of Mines are directed primarily toward improving the economics of this step.

Preliminary data for pilot-plant investigations are obtained in the laboratory on a small scale using batch autoclaves and methods which have been described previously (*4*). The early pilot-plant work considered the available types of feed stock and the effects of certain process variables. Data on the amenability to hydrogenation of typical United States coals were obtained (*10*). A series of runs considering the effects of temperature and contact time also has been reported (*3*). In this latter work it was shown that fuel oil meeting the requirements of A.S.T.M. 6-grade could be produced by the hydrogenation of coal at pressures of 3500 to 4500 lb./sq.in. A recent paper on pilot plant scale catalyst testing verifies previous batch laboratory data and also reports on middle oil production from coal (*6*).

The belief that some advantage exists in the conversion of coal to heavy oil at low pressures is not recent. The Pott-Broche (*8*) extraction process solvated coal using tetralin-cresol-naphthalene mixtures with essentially no hydrogen absorption and without hydrogen pressures except that produced in the process. Storch (*9*) reports the results of a research program started during the World War II for the production of fuel oil from coal at a pressure of 1,000 lb./sq.in. In both these cases the temperature of operation had to be relatively low (380° C. to 420° C.) to avoid coking difficulties. As a result, long contact times were required in the low-pressure hydrogenation. The solvent action of the vehicle reduced the contact time required in the extraction process, but the resulting coal extract was not suitable for fuel-oil use and further treatment by hydrogenation was found to be uneconomical. It was used as a low-ash raw material for the manufacture of carbon electrodes.

The present paper reports a series of pilot-plant studies of the conversion of Rock Springs Coal (D. O. Clarke Mine No. 9, Superior, Wyo.) into fuel oil at an operating pressure of 1500 lb./sq.in. Although this is by no means a low-pressure operation, it represents a considerable decrease in the pressures (4,000 to 10,000 lb./in.) normally used in European industrial coal-hydrogenation plants. In addition, 1500 lb./sq.in. represents an upper limit above which it becomes increasingly difficult to use standard, easily available equipment.

Mechanism and Catalysis

The problems associated with low-pressure hydrogenation of coal can be considered conveniently in the light of a postulated mechanism for coal hydrogenation. H. Broche (*1*), C. M. Cawley (*2*) and more recently Weller et al (*11*) suggest that coal is first thermally split into reactive fragments which subsequently either polymerize to form benzene-insoluble material refractory to hydrogenation or are stabilized by the addition of hydrogen to form benzene-soluble materials. Either of these steps might be catalyzed or affected by process conditions of pressure and temperature. Batch autoclave data (*7*) show the following: If the partial pressure of hydrogen is reduced at a fixed temperature, at some pressure the rate of stabilization of the reactive fragments (formed at a rate dependent on temperature), becomes sufficiently slow to permit their polymerization to insoluble materials. If the pressure is fixed at a level where hydrogenation takes place easily and if the temperature is raised, the amount of benzene-insoluble material produced in the reaction reaches a minimum and then begins to increase.

In order to operate a plant at a temperature high enough to permit a reasonably low reaction time and avoid formation of solids, some means must be employed either to retard selectively the polymerization of the fragments or to increase selectively the rate of their hydrogenation. In the low-pressure hydrogenation experiments reported by Storch (*9*), low reaction temperature and long contact time reduced the formation of insolubles. In solvation of coal, the special solvents used minimized formation of insolubles and made operation possible.

Catalysis of the coal-hydrogenation reaction has been covered quite adequately in the literature. It is almost certain that each metallic element with any potential catalytic promise has been tested alone and in combination with other elements for its activity as a catalyst. The data and literature survey furnished by Weller et al (*13*) give the results of several comparative studies. It is reported that, of the many combinations tested, tin (in any form) pro-

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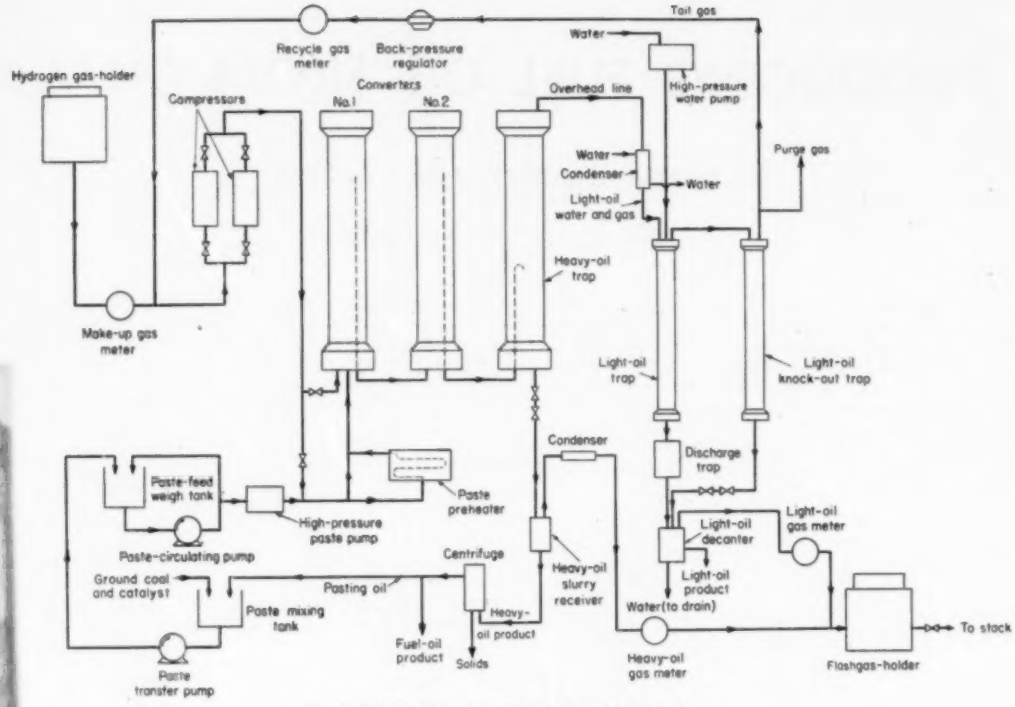

Fig. 1. Schematic flow diagram, fuel oil experimental plant.

moted with hydrochloric acid gives the best results in the conversion of coal. Recent autoclave experiments at the Bureau of Mines (*12*) have shown a marked beneficial effect when certain catalysts are impregnated on the coal surface by using water solutions. This improvement in catalyst activity was large enough to suggest the possibility of using these catalysts to decrease the pressure of operation.

Description of Plant. A simplified flow sheet of the coal-hydrogenation pilot plant is shown in Figure 1. This plant, originally designed for operation at 4500 lb./sq.in., has been described in detail (*3,6*), but, as in most experimental units, has undergone some minor changes. Crushed, dried coal is ground to 90% through 200 mesh, treated with catalyst, by mixing the crushed coal with an equal volume of water solution of catalyst, redried at 150° F. in a tray drier, mixed with recycled centrifuged heavy oil in batches sufficient for eight hours' operation, and the resulting 35 wt. % coal-in-oil paste is fed via a circulating pump to a high-pressure injection pump.* Hydrogen is drawn from a 60,000-cu.ft. gasholder by a 5-stage reciprocating compressor. The coal paste-hydrogen mixture passes through two reactors in series. These reactors are 3-in. internal-diameter tubes fitted with removable liners of 2-in. extra-heavy pipe, the feed entering at the bottom and leaving via an internal standpipe. The reactors are heated electrically; part of the first reactor is used to preheat feed to reaction temperature. The reaction volume, allowing for internal thermocouple wells and standpipe, is 200 cu.in. for each reactor. From the second reactor, the products pass into a heavy-oil trap fitted with a reflux coil and maintained at 100° C. where the heavy oil is removed through manually operated pressure let-down valves. The heavy oil is centrifuged, after sampling, to remove solids, and part of this centrifuged oil is used to make paste for subsequent feed; the remainder of the centrifuged heavy oil is taken as product. Vapors leaving the high-pressure heavy oil separator are cooled by direct injection of water, and some light oil is condensed. This water-washing removes the bulk of the hydrogen sulfide, ammonia and other soluble products and, after passing through an additional liquid trap, the uncondensed overhead gas (tail gas) is reduced in pressure and returned to the compressor suction line. A constant purge of recycle gas (purge gas) is taken to maintain a predetermined hydrogen purity.

* The normal procedures for adding catalysts are either to mix the catalyst in powdered form with the coal-recycle oil paste or to prepare a catalyst-oil slurry and add this slurry to the coal-recycle oil paste.

Plant Operation and Control

The plant balance is dependent, of course, on metering and analyzing inlet and outlet streams. The inlet streams include the coal paste fed from a weighing tank and the make-up hydrogen delivered from a gasholder through a bellows-type gas meter to the compressor. The inlet scrubbing water is measured by taking periodic levels on the water feed tank. Two liquid products, heavy oil and light oil plus water, are weighed after reduction in pressure. The product gas streams, flashed off when liquid products are reduced in pressure, are metered, combined with the metered purge, and collected in a common gasholder where a composite sample is obtained for analysis.

The plant data are made consistent with a carbon and material balance over the plant by correcting the observed gas production and the total paste feed. In general these corrections are small percentages of the observed values. The hydrogen consumption is obtained by metering make-up hydrogen to the compressor and subtracting the hydrogen content of the tail and purge gas streams. The nitrogen, sulfur and oxygen removal is obtained by ultimate analysis of feed and product and used to calculate ammonia, hydrogen sulfide and water produced in the hydrogenation. Analytical techniques and the details of obtaining plant balances and

estimating equivalent contact time at some particular specified temperature in a reactor having some variation in temperature have been described in detail (*6*).

Because liquid-phase coal hydrogenation is a recycle operation, a number of operating periods must be completed so that an "equilibrium recycle oil" is used for preparing coal-paste feed before reliable results can be obtained. This problem is a common one in any pilot-plant investigation where a recycle stream is employed but is of possibly greater importance in this case because of the recycle oil-to-coal ratio. A rough picture of the time required to stabilize the plant operation is given in Figure 2 where viscosity (SSU at 180° F.), asphaltene content (asphaltene is defined as material soluble in chloroform and insoluble in *n*-hexane), and chloroform-insoluble material content for product heavy oil are given for each 8-hr. operating period (batch). Data plotted include a change in operating conditions where the paste feed rate is increased from 10 lb./hr. in test *A* to 17 lb./hr. in test *B* with all other conditions constant. After the first three or four batches of test 3, a fairly uniform product oil was obtained according to the analyses plotted as criteria. Almost twice this length of time is required at a lower feed rate. As each series of tests on a new catalyst is started with a catalyst-free topped tar-oil, the first test period of several 8-hr. batches with each catalyst is usually discarded, and this period is utilized to increase the coal concentration to operating requirements from a lower start-up concentration of 20 wt. % and to check the mechanical operation of plant equipment.

Experimental Data. Yields obtained in the pilot plant using four different catalysts are given in Table 1. In all cases, a high-volatile *C* bituminous coal of the Rock Springs bed (D. O. Clarke Mine, No. 9, Superior, Wyo.) was used. This coal has the typical (as received) ultimate analysis as shown in Table A.

TABLE A

	Wt. %	
C	71.1	
H	4.9	
N	1.5	
S	0.7	
O	13.3	(by difference)
Ash	6.8	
H_2O	2.2	

Catalysts tested are all used in soluble form to permit impregnation of the coal by a water solution of the catalyst: molybdenum as ammonium molybdate; nickel as nickel(ous) chloride; tin as stannous chloride; iron as ferrous sulfate. Nickel, iron and tin had been tested in the pilot plant at 3500 lb./sq.in. and both nickel and iron, while not as active as tin for the conversion of coal, showed some promise (*6*). Nickel particularly gave good evidence of being at least as active as tin in the reduction of asphalt, while the low cost or iron catalyst made the use of higher catalyst concentration possible to counteract its low activity. Molybdenum catalyst gave promise in autoclave tests of being superior to tin which has been considered the best catalyst known for coal hydrogenation (*12*). In order to obtain this high activity it was necessary to neutralize the alkalinity of the coal, and this was done by adding sulfuric acid to the ammonium molybdate solution used for the impregnation of the coal. The coal used required an average of 7.4 g. of sulfuric acid/kg. of coal for complete neutralization. To prevent corrosion only 70% of the alkalinity of the coal was neutralized in pilot plant operation.

Two paste feed rates were tried with each catalyst: approximately 10 and 16-17 lb./hr. Temperature, pressure, and hydrogen circulation rate were kept constant in all except one case. (Run 13, test 5 repeats test 2 with a decreased hydrogen circulation rate.) Each catalyst was run at two contact times, and, in the case of nickel catalyst, run 12 repeated run 11*D* with the addition of baffles in one of the two converters.

Examination of Table 1 reveals only minor differences between the various catalysts as far as gross product distribution is concerned with the exception of run 14, test 3. In this particular case, use of iron catalyst at a contact time of approximately half an hour gives a low oil yield and a higher yield of benzene-insoluble material than any of the other tests listed. In fact, the fraction of the coal charged which is converted to liquid and gas (100 minus the organic material insoluble in benzene) is sufficiently low as to make extended continuous operation under these conditions rather doubtful. The high oil yield listed for iron catalyst at 0.51 hr. contact time (run 14, test 3) is somewhat misleading. When this operation was continued increasing solids forced a shutdown of the plant. Using the balance of the data of Table 1, it is difficult to make any conclusions about the relative activity of the remaining three catalysts. This is due to the large quantity of recycle oil relative to coal in the feed (65% oil and 35% coal). This oil is susceptible to both thermal cracking and hydrogenation in its passage through the plant, and some of the oil and gas production observed is a result of reactions of the recycled oil. Correction of the yield calculations for recycle oil to obtain the product distribution from coal thus exerts a dampening effect on any variations.

The anticipated increase in hydrocarbon gas production with an increase in contact time can be observed for all catalysts tested. The molybdenum catalyst seems to produce higher hydrocarbon gas yields than any of the other catalysts. One would expect higher

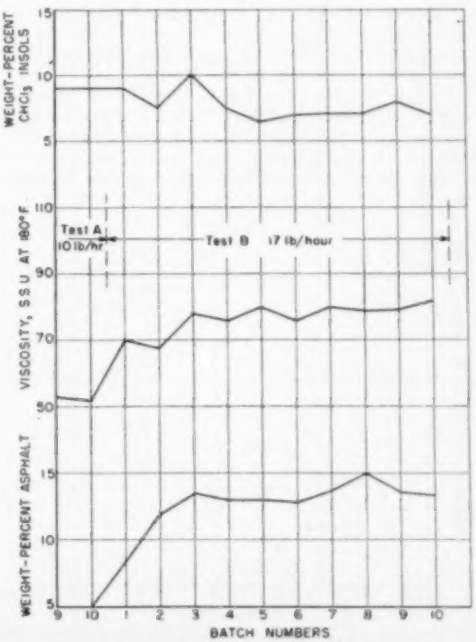

Fig. 2. Effect of change in feed rate on heavy oil product.

water yields as contact time is increased due to better oxygen elimination. This is indeed so for all catalysts except iron, and in the case of iron the plant operation at the lower contact time was quite unsteady and the data somewhat less reliable.

To avoid this obscuring effect, it is convenient to study the behavior of the plant relative to total feed. Two useful criteria can be calculated: the per cent "organic insolubles remaining," defined as:

$$100 \times \frac{\text{organic insolubles in heavy oil, lbs.}}{\text{organic insolubles in pasting oil, lbs.} + \text{m.a.f. coal, lbs.}}$$

and the per cent "asphaltene remaining," defined as:

$$100 \times \frac{\text{asphaltenes in heavy oil, lbs.}}{\text{asphaltene in pasting oil, lbs.} + \text{m.a.f. coal, lbs.}}$$

The m.a.f. coal is regarded as being either all organic material insoluble in benzene or potential asphaltene, respectively. These values are plotted in Figures 3 and 4 for the four catalysts tested. The points for individual data periods have been used in these plots as opposed to the data in Table 1, which gives average test values for several data periods. There is considerable scattering, and the lines drawn should be considered as representing approximate levels of activity rather than exact loci. Data for molybdenum at the longer contact time were particularly widely separated, and several of the points were omitted from consideration in drawing the curve shown. It is believed that, in spite of these uncertainties, as far as organic insolubles remaining, the order of decreasing activity in these catalysts is as follows: molybdenum, tin, nickel and iron. In evaluating asphalt reduction, the same order is found to be correct, with nickel and tin approximately equal. These data on the relative activity of the catalysts tested show good agreement with batch autoclave data (*12*).

Table 1.

Yields and Hydrogen Consumed

(1500 p.s.i.g., 460°C., 600 CFH hydrogen circulation rate
Rock Springs Coal)

Run	Test	Catalyst	Paste Feed Rate, lb./hr.	Contact Time, hr.	H₂ Abs., Wt.-% Coal	Yields, Weight-Percent m.a.f. Coal						
						Hydrocarbon Gas	Water	Soluble Oil	NH_3	H_2S	$CO + CO_2$	Organic Insolubles
11B	2	0.5% Ni (a)	10.4	0.50	6.2	2.6	13.7	54.8	0.7	0.1	1.7	12.7
	3	do	10.5	.58	4.6	1.5	11.0	61.5	0.7	0.2	2.9	13.8
12	2	do	10.4	.97	6.0	2.8	11.0	55.3	0.6	0.4	1.9	12.0
	3	do	10.4	.58	4.3	1.5	7.6	63.4	0.4	0.5	1.9	10.0
13	2 & 4	0.5% Mo (b)	10.1	1.09	8.6	2.2	15.0	53.0	0.6	0.9	1.9	12.7
	3	do	10.7	.59	5.5	1.5	10.0	13.1	62.7	0.8	0.8	0.9	9.3
	5	do (c)	10.2	1.01	5.4	1.9	8.6	63.8	1.2	0.3	1.4	11.1
14	2	1.0% Fe (c)	9.9	0.98	4.7	1.9	9.5	60.6	0.7	0.5	2.6	12.6
	3	do	10.8	.51	3.9	1.2	12.6	53.1	0.3	0.5	3.2	23.0
15	2	0.5% Sn (d)	10.1	1.04	6.1	2.6	12.1	61.5	1.1	0.7	1.5	8.3
	3	do	10.6	.58	4.7	1.5	9.6	66.5	1.1	0.7	1.4	10.4

(a) 0.5% Ni on coal as charged added as nickelous chloride
(b) 0.5% Mo on coal as charged added as ammonium molybdate; coal neutralized with sulfuric acid
(c) 1.0% Fe on coal as charged added as ferrous sulphate
(d) 0.5% Sn on coal as charged added as stannous chloride
(e) Hydrogen circulation rate reduced to 300 CFH

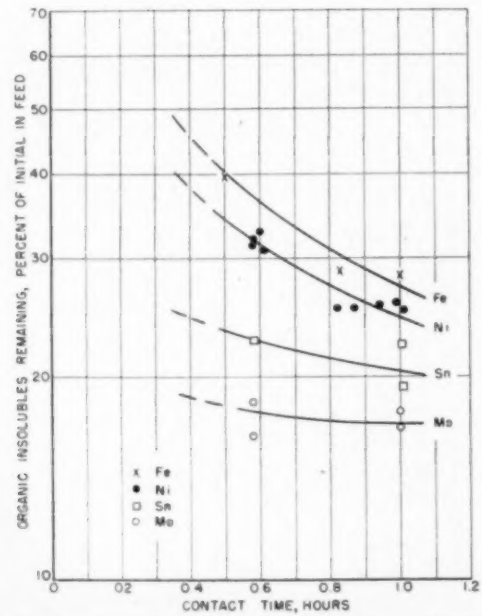

Fig. 3. Effect of catalyst on organic insolubles remaining, Rock Springs coal, 1500 lb./sq.in gage at 460° C.

Still another criterion of catalyst activity having, possibly, more practical significance is the character of the uncentrifuged heavy oil produced. The average analyses of heavy-oil products obtained in the various tests are listed in Table 2. The material obtained with molybdenum catalyst is of superior quality, having lower viscosity, asphalt insolubles, and sulfur contents and a higher percentage of hydrogen and oil distillable to 355° C. It is quite feasible to use product oils obtained with other catalysts as heavy fuel oil. The ash contents are reduced to below 1% by the centrifuging operation normally used to remove solids in the plant operation. The lower throughput tests (11 *D-2*, 12-2, 14-2, 13-2 and 5, and 15-2) all produce fuel oils of proper viscosity and ash content. Consideration of these analytical data, however, does substantiate the good activity of molybdenum catalyst even when compared with tin for this type of operation with this particular coal.

After the initial run at pressures of 1500 lb./sq.in. which was performed with nickel catalyst (run 11*D*), it was felt that one reason for the success of

the operation might be the increased agitation obtained from the flow of a larger volume of hydrogen gas at reaction conditions compared with that flowing in previous high-pressure pilot-plant runs. A glass mock-up of the reactor liner was constructed with water and air substituted for the coal-paste feed and hydrogen, respectively, to obtain some comparison of the high-pressure and low-pressure reactor operation. The change in gas velocity due to increased volume at pressures of 1500 lb./sq.in. gage compared to 3500 lb./sq.in. gage was sufficient to give considerable turbulence as estimated by visual examination. There appeared to be enough turbulence, possibly, to approach the case of a completely mixed reactor. It was decided to insert five baffles into the second converter and thus subdivide the reaction volume into six separate mixing chambers. This subdivision could be expected to give a considerable increase in the conversion if the original reactor were considered to be completely mixed, and the reaction assumed to be a first-order reaction. Both these assumptions are only partly possible, and it was not too surprising to observe little if any improvement in the data obtained in run 12 when compared with run 11*D* (Tables 1 and 2).

An attempt to evaluate the effect of turbulence was made in run 13 where the conditions of tests 2 and 4 with molybdenum catalyst are repeated in test 5 with the hydrogen circulation rate reduced from 600 std. cu.ft./hr. to 300 std. cu.ft./hr. No apparent decrease in conversion is noted as a result of the decrease in hydrogen flow rate. Some improvement in light-ends recovery can be observed in the increased production of material distillable to 300° C. (see Table 2). Although the above results are not conclusive, it would appear that the effect of turbulence due to gas flow is not large in the range investigated.

Comment

The prime purpose of most pilot-plant work is to examine the feasibility of a process or a set of processing conditions for possible large-scale application.* In order to evaluate the results, it is necessary to know the effect on the yield data of enlarging the plant. For illustration purposes, the yield data obtained in test 3 of run 12 have been converted to petroleum engineering units in Table 3, and additional data have been added indicating composition of the hydrocarbon gas produced all based on a ton of coal as charged to the plant (1830 lbs. of moisture-and-ash-free coal). It should be realized that the product data are obtained by analyses performed on a total stream and the recoverable products may be somewhat less depending on the plant separation techniques used. For example, the "oil produced" value of 3.16 bbl. represents oil containing 16% of insoluble material, and, while the solids are not included in the quantity of soluble oils given, some oil is lost in removing the undesired solids. The hydrogen used in the pilot plant is calculated by the difference in hydrogen content of incoming and outgoing streams, and this method of calculation corrects for the hydrogen gas mixed with gas-

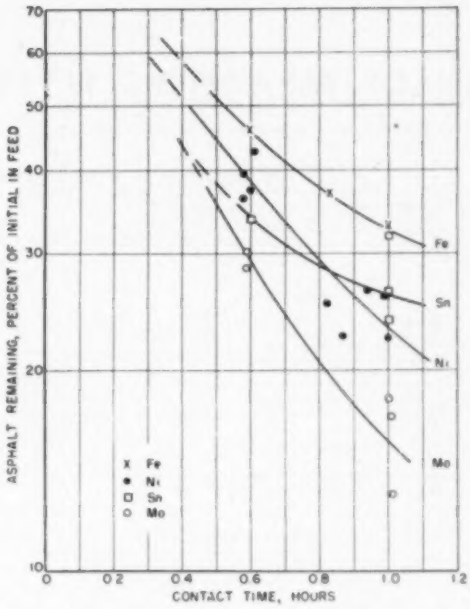

Fig. 4. Effect of catalyst on asphalt remaining, Rock Springs coal, 1500 lb./sq.in. gage at 460° C.

Table 2

Product Oil Characteristics

(1500 p.s.i.g., 460°C., 600 CFH hydrogen circulation rate
Rock Springs Coal)

Run	Test	Catalyst	Contact Time, Hr.	Viscos., SSU at 100°F.	% Tetra. Insol.	% Asphalt	ASTM Distillation, % off to 205°C.	to 300°C.	C	H	N	O	S	ash	H2O
11C	2	0.5% Mo	0.90	175.7	13.0	10.9	23.6	44.1	87.9	6.6	1.2	0.3	0.2	2.0	2.3
	3	do	.58	139.5 (a)	17.2	17.4	25.6	41.8	85.6	6.6	1.2	1.7	.3	2.9	2.0
12	2	do	.97	137.0	13.1	12.6	30.6	47.2	88.9	6.7	1.2	2.2	.3	1.8	.9
	3	do	.58	133.6 (a)	15.1	15.3	28.6	45.3	84.7	6.6	1.2	3.1	.3	2.3	1.3
13	2 & 4	.5% Mo	1.09	58.6	0.5	7.1	46.5	65.4	89.2	7.5	1.2	.9	.1	.4	.7
	3	do	.59	62.4	7.6	13.7	37.5	53.6	88.7	7.4	1.2	1.8	.1	.5	.3
	5	do	1.01	55.3	1.6	8.1	46.5	72.1	89.5	7.6	1.1	0.6	.2	1.1	1.1
14	2	1.0% Fe	0.98	258.5	14.3	4.0	23.7	34.0	87.6	6.7	1.3	1.9	.4	1.9	.9
	3	do	.51	203.7 (a)	20.6	21.9	22.5	39.3	85.8	6.6	1.4	0.3	.6	3.8	.3
15	2	0.5% Sn	1.04	116.9	10.7	13.1	33.4	51.2	88.2	6.7	1.1	0.1	.2	1.3	.1
	3	do	.59	157.4	17.8	15.6	26.8	45.1	86.7	7.2	1.2	2.6	.2	1.5	.2

(a) Viscosity given in SSF at 140°F.

* Detailed data on gas composition, tar acid and tar base production and boiling ranges of oil products are available and may be obtained by writing the authors at the Bureau of Mines, 4800 Forbes Street, Pittsburgh, Pa.

TABLE 3.—YIELD DATA

Basis - 1 ton coal as charged (1830 lb. m.a.f. Rock Springs coal)

Processing Conditions: 1500 p.s.i.g., 460°C., 2% catalyst

Salable or Usable Products

Oil	3.2 Bbl. (42 gal. 8.74 lbs./gals.)
Hydrocarbon gas	3720 cu. ft.
Ammonia	7.3 lb.
Hydrogen sulfide	9.1 lb.
*Tar acids	18.3 lb.
*Tar bases	9.1 lb.

Hydrocarbon-Gas Analysis

	Vol. %
Methane	60.1
Ethane	20.9
Propane	7.3
Butane	5.8
Butylenes	.8
Pentane	1.4
Pentene	1.8
Hexane	2.0
	100.0

Processing Requirements

Hydrogen (100%)	14,400 cu. ft.
Nickel	10 lbs.

*Tar acids and bases included in oil product.

eous hydrocarbons in the product gas streams. This hydrogen gas is not completely recoverable, and some hydrogen must be lost in a large plant via purge streams to keep the noncondensable gas content under control. Thus, the value listed in the yield data will be increased for a large plant with the increase depending on the gas-producing and recovery methods.

It can, therefore, be concluded that a ton of this coal will produce approximately 3.2 bbl. of fuel oil, 3500 cu.ft. of hydrocarbon gas, and possibly 35 lbs. of recoverable by-products. (Ammonia, hydrogen sulfide, tar acids and tar bases). This will require more than 15,000 cu.ft. of hydrogen/ton of coal. The catalyst requirement of 10 lb. of nickel/ton of coal is high, but the bulk of this catalyst is concentrated in the residue obtained on centrifugation and might be recoverable. Comparing these results with high-pressure hydrogenation of coal to produce heavy fuel oil is reported by Hirst et al. (5), it is found that at 700 atm. pressure (10,300 lbs./sq.in. gauge), 3.7 bbls. of oil of similar quality, 2,000 cu.ft. of hydrocarbon gas, and somewhat higher quantities of recoverable by-products are obtained. Because of the lower hydrocarbon gas production, the hydrogen gas consumption is only 12,000 cu.ft. using only the "reaction hydrogen" which is comparable to the value obtained in our pilot-plant data.

It would appear that for a fuel-oil operation, while the total plant investment costs may not be considerably decreased for the low-pressure plant because of larger hydrogen-production facilities needed, the ability to use standard Series 150 piping materials for much of the plant and welded rather than forged vessels should make this type of plant more easily available in national emergencies or in localities where fuel oil is obtained only through import. Such areas as Australia, South Africa, and Alaska, for example, could use this process to produce oil for refueling naval and merchant shipping without dependence on tanker shipments.

Acknowledgment

The authors wish to acknowledge the assistance of the many people involved in the performance of the experimental work, calculation of the data, analyses of the products, and illustrating this paper; particularly the assistance of A. Pipilen, J. Nanz, W. R. Wilson and the operating and maintenance men under their supervision who made possible the assembly and operation of the plant; W. Rosinski for his supervision of the proximate and ultimate analyses; R. A. Friedel and his staff for the mass spectrographic analyses; M. Corrado and S. Wekselman for their assistance in calculation of the data, and J. Vidosh and E. Ralston for preparation of the figures.

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Discussion

Norris Shreve (Purdue University, Lafayette, Ind.): Did you recover, economically, any of your catalysts?

E. L. Clark: We have been looking at that particularly from the point of view of molybdenum recoveries, and we don't think the recovery will materially decrease the catalyst cost. We may obtain a more highly enriched molybdenum ore by ashing the residues from the coal hydrogenation process. The normal methods of recovering molybdenum from its ore would still have to be utilized. Right now, the catalyst costs are high, since we are using a half per cent of molybdenum. We have been doing some work on reducing this amount of molybdenum and recent batch autoclave tests have indicated that we can get down to about 0.1% molybdenum, which should make the catalyst cost about 30 cents/bbl. of oil. This is based on producing 3-4 bbl. of oil/ton of coal.

(*Presented at Forty-third Annual Meeting, Columbus, Ohio.*)

FREEZE DRYING WITH RADIANT ENERGY

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University of Wisconsin, Madison, Wisconsin

A preliminary experimental study was made of freeze drying with radiant energy according to the teaching of the Levinson-Oppenheimer patent. Frozen material retained on a supporting medium transparent to infrared radiation was dried with radiant energy emitted from electrically heated wires. Drying time curves were obtained for various conditions of cake thickness, initial moisture content, and energy concentration.

IN the drying of certain heat-sensitive materials, special low-temperature drying techniques are required often to preserve the quality and value of the product. It has been found possible to dry and maintain the potency of biologicals, the solubility of pharmaceuticals, and the flavor and aroma of foods and extracts by a method which has become designated as freeze drying. By this process, a material is dried in vacuo in the frozen state by subliming the water as ice rather than evaporating it as a liquid.

The drying of heat-sensitive materials from the frozen state is a long-established art. However, widespread industrial application of this drying method occurred only during and since World War II.

In freeze drying, as it has been practiced in commercial operations, the heat of sublimation is conducted to the frozen material through a solid-retaining medium heated by circulating liquids or gases. Levinson and Oppenheimer (*11*) discovered, however, that marked advantages could be obtained if the heat for sublimation were transferred, in part, by radiation rather than by conduction alone. They found that due to the penetrating effect of radiant energy in suitable wave bands it was possible by the proper selection of a transparent supporting medium, both to increase the drying rate and decrease the possibility of melting the frozen material in contact with the supporting medium.

Since this work constituted the initial stages of an extensive study of freeze drying, the findings reported in this paper are to be regarded as preliminary in nature. One objective of the initial work was to describe the mechanism of freeze drying more clearly than has been done heretofore. It should be emphasized that this study was made neither to improve product quality of specific substances nor to study the drying of biological materials. Rather, was the objective to study freeze drying in the more usual chemical engineering manner by establishing drying time curves under various conditions of operation.

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Previous Investigations

Relatively little work has been reported on freeze drying with radiant energy. Levinson and Oppenheimer (*10*) described the first significant study on the drying of blood plasma by radiant freeze drying. They reported that it was possible to reduce the usual drying time of 48 to 96 hrs. by conduction to 24 hrs. by the use of radiant energy in conjunction with suitably selected transparent supporting media.

In drying blood plasma, Levinson and Oppenheimer used glass bottles. To determine a source temperature which would cause a high percentage of the radiant energy to be transmitted by the glass, they made tests with electrically heated wires at temperatures from 100 to 1,000° C., at 100° C. intervals. At wire temperatures of 100, 200, and 300° C., melting had occurred in the plasma adjacent to the glass and there was residual moisture. At 800, 900, and 1,000° C., the material in contact with the glass was burned while the inner surface remained frozen. When the wire temperatures were 400, 500, 600, or 700° C. the samples were uniformly dry. It was claimed that this experiment demonstrated the importance of selecting radiant energy in the proper wave-length range. Penetration of radiant energy was detected also by means of a vacuum thermopile located on the side of the sample away from the source of radiation.

Reavell (*14*) showed the advantages of penetration in depth with radiant energy in applications to distillation and evaporation. Wilhelm and Smith (*19*) reported experimental evidence of penetration of radiant energy in the infrared drying of textiles. On the other hand, Flosdorf (*5*) stated without further discussion that radiation does not readily penetrate ice or the dry layer of the product so that no great gain in efficiency could be expected from the use of radiant energy.

Stout, et al (*18*) reported that the penetration of radiant energy did not exceed 1/16 in. in the drying of sand and soap at atmospheric pressure. However, they reported substantially higher drying rates over other drying methods and attributed this to the fact that there was no gas- or liquid-film resistance to the flow of heat as in convection, and no direct contact required as in conduction.

These conflicting conclusions may be due, in part, to the fact that materials of different absorption characteristics were dried, and the temperatures and accordingly the wave bands of the radiant sources were quite different.

Patents by Elser (*4*) and Barr (*2*) describe the advantages to be gained by drying in the frozen state. A patent by Reichel (*15*) describes freeze drying with heat transfer by conduction.

Hormel (*9*) proposed the use of visible radiant energy to dry frozen solids, and advocated keeping the frozen particles agitated so that as drying proceeds the dried material is removed from the particles by attrition, thus exposing a continually fresh surface for sublimation.

Flosdorf (*7*) proposed letting the heat generated by the adsorption of water vapor on solid desiccants radiate to the frozen material and sublime the ice. Such a procedure is inflexible, and the radiant energy is restricted to a low-temperature level.

Schroeder, Schwarz, Penn and Cotton (*16, 17*) outlined the advantages of low-temperature vacuum drying with conduction heating. Much of their work was done with the material in the liquid state, however, and it was claimed that not only were the drying rates for the liquid state greater than for the frozen, but also in addition the quality of the materials studied was not significaqtly impaired.

Ede (*3a*) reported a fundamental study of freeze drying by conduction, and considered the problem of vapor flow to the condenser.

In a recent book, Flosdorf (*6*) has described current commercial practices in conduction freeze drying.

Fundamentals of Freeze Drying

1. *Distinction Between Freeze Drying and Conventional Drying.* In the drying of a wet solid that is not frozen, the water is removed by evaporation

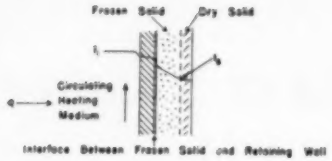

Fig. 1.

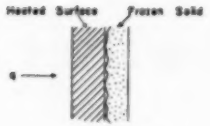

Fig. 2.

Interface conditions in freeze drying.

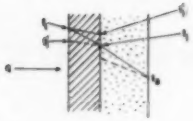

Fig. 3.

from a *liquid* surface. As the drying progresses, the material may shrink and form hard, impervious agglomerates. Likewise, there is generally a movement of liquid water within the solid during drying.

In the case of freeze drying, water in the form of ice is removed by sublimation, which is direct vaporization of ice to water vapor without passage through the liquid state. Since the material is not fluid at these low temperatures, the dry solid tends to retain its original shape and generally occupies the same volume when dry as it did when wet. Further, since the ice is relatively immobile, freeze drying is usually accompanied by a retreating ice layer into the solid, and away from the exposed surface.

In the drying of wet solids that are not frozen, the rate of drying is often constant during the initial part of the drying cycle. In this case the water is transported to the surface as rapidly as evaporation can remove it, and the rate of drying is controlled by the rate of vapor diffusion through a gas film adjacent to the solid. However, at some critical moisture content, the water can no longer flow to the surface as fast as it is removed. At this moisture content, the zone of evaporation begins to recede into the solid, and the rate of evaporation starts to decrease. This phase usually is termed the first falling-rate period of drying. A second falling-rate period occurs when moisture held by the solid at reduced vapor pressure begins to evaporate.

In the drying of frozen materials the ice at the surface exposed to the vacuum sublimes first. Since the ice is not free to move, the zone of sublimation or drying immediately starts to recede. However, since the solid usually retains its original structure or shape there is a large percentage of voids through which vapor can diffuse. Thus, the drying rate remains substantially constant until near the end of the drying cycle when bound moisture is sublimed. However, even in freeze drying, this terminal drying period is of considerable significance and usually represents a controlling factor in determining the over-all drying time.

2. Characteristics of Conduction Freeze Drying. In conduction freeze drying, water or some other heating medium is circulated in contact with the container holding the frozen material. The container is thus heated by conduction and in turn conducts heat to the frozen material in contact with it. Heat then flows through the sample to the exposed ice surface where sublimation is occurring. Since the thermal conductivity of ice and most organic materials is low, the rate of heat transfer will be low if the frozen material at the interface must be maintained frozen.

Referring to Figure 1 showing the temperature gradients in conduction freeze drying, the following heat-transfer equation for plane surfaces may be written in terms of the various thermal resistances involved:

$$\frac{q}{A} = \frac{(t_1 - t_s)}{\frac{1}{h_l} + \frac{B}{k_m} + R_i + \frac{x}{k_s}} \qquad (1)$$

where

q/A = heat flux, B.t.u./(hr.)(sq.ft.)
t_1 = temperature of heating medium
t_s = temperature of surface of sublimation
h_l = film heat-transfer coefficient of heating medium, B.t.u./(hr.)(sq.ft.)(°F)
B = thickness of retaining medium, ft.
k_m = thermal conductivity of the retaining medium, B.t.u./(hr.)(sq.ft.)(° F./ft.)
R_i = thermal resistance at interface between frozen solid and retaining medium
x = thickness of ice layer in solid
k_s = thermal conductivity of solid-ice mixture

From Equation (1) it is evident that the rate of heat transfer and hence the rate of sublimation is dependent on four thermal resistances. Of these, $1/h_l$ and B/k_m are usually quite small compared with R_i and x/k_s, and these may be considered to be controlling. The rate of conduction freeze drying, therefore may be said to be controlled by the following factors: (1) How well the frozen solid adheres to the heated retaining medium; i.e., how small R_i can be made, (2) by the thickness of the frozen solid, and (3) by the thermal conductivity of the ice-solid mixture. This assumes there is no resistance to mass transfer or the flow of vapor through the dry solid. In some cases, mass transfer may be a controlling factor.

The thermal resistance at the interface between the frozen solid and the retaining medium is a major factor in determining the rate of heat input and hence the rate of freeze drying. If the resistance is high, the heat input must be kept low in order to avoid overheating the material which is in contact with the retaining medium. This may be pictured by means of the following analysis:

Let Figure 2 represent the actual case of a frozen solid in contact with a heated surface. The representation shown indicates that intimate and uniform contact with the heated surface may not be achieved. This is often the case in practice, such as when a material is sprayed and frozen onto a belt in a vacuum. As a result, heat is transferred along two paths in parallel, namely, (1) by solid conduction at the points of contact, and (2) by vapor conduction and low temperature radiation where contact does not occur. The resistance along the latter path is much higher than along the first. The total heat transferred per unit time then becomes equal to the sum of the heat flow for both paths, or

$$q = q_1 + q_2 \qquad (2)$$

The heat conducted through the areas of contact, q_1, may be written

$$q_1 = k_s A_1 \left(\frac{dt}{dx}\right)_i \qquad (3)$$

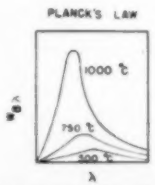

Fig. 4. Typical curves based on Equation (11).

where

k_s = thermal conductivity of the ice-solid mixture at the interface

A_1 = area in contact with heated surface

$(dt/dx)_i$ = temperature gradient in the ice at the interface, and dx is measured in the negative direction

An expression for q_2 may be written as

$$q_2 = \frac{A_2 \Delta t}{R_i} \qquad (4)$$

where

Δt = average temperature drop across the vapor space where no contact occurs

A_2 = area of the heated surface not in contact with the frozen solid

R_i = thermal resistance of the vapor space

Combining Equations (3), (4), and (2), the total heat transferred becomes

$$q = k_s A_1 \left(\frac{dt}{dx}\right)_i + \frac{A_2 \Delta t}{R_i} \qquad (5)$$

The thermal resistance R_i may be written as $\Delta x/k_v$, where k_v is considered as the effective thermal conductivity of the vapor space, and Δx is the thickness of this space. The effective conductivity is intended to include any low-temperature radiation which may occur. Then Equation (5) becomes

$$q = k_s A_1 \left(\frac{dt}{dx}\right)_i + k_v A_2 \left(\frac{\Delta t}{\Delta x}\right) \qquad (6)$$

where $(dt/dx)_i$ and $(\Delta t/\Delta x)$ do not have the same value.

In general $k_v << k_s$, since the thermal conductivity of a gas is quite small compared with that of the solid. This means that the second term will contribute much less to the total heat flow than the first term for equal values of A_1 and A_2. The important variables to consider now are A_1 and A_2. For good contact, A_1 will be large and A_2 will be small, while, conversely, when contact is poor, A_2 will be large and A_1 will be small. If it is required that the interface temperature cannot exceed some maximum value then it is apparent that q must decrease as A_2 increases, i.e., the rate of freeze drying must be decreased. This is evident from the equation for t_i, the temperature at the interface,

$$t_i = t_1 - \frac{q}{k_m A/B} \qquad (7)$$

where

t_1 = temperature on the "hot side" of the heated surface

k_m = thermal conductivity of the retaining medium

Substituting Equation (6) in (7) gives

$$t_i = t_1 - \left[\frac{k_s f_1 (dt/dx)_1}{k_m/B} + \frac{k_v f_2 (\Delta t/\Delta x)}{k_m/B}\right] \qquad (8)$$

where $f_1 = A_1/A$ and $f_2 = A_2/A$, and $f_1 + f_2 = 1$.

Since f_1 and f_2 are linearly dependent on each other, an increase in f_2 will tend to decrease the total value of the quantity in brackets and hence increase t_i. Increasing f_2 means increasing the amount of poor contact. Thus, in order to keep t_i below some specified temperature, t_1 must be lowered, thereby lowering the heat flux and the rate of drying.

The above considerations may be illustrated graphically, with reference to Figure 3. For good contact or a value of f_1 nearly one, the temperature drop through the heated retaining medium is $(t_1 - t_i)$. If f_1 decreases or f_2 increases, then t_i rises to t_i'. This means that the portion of the frozen solid in contact with heated surface is raised, and may exceed the permissible maximum temperature with melting at the interface as a result. The principal temperature drop at the interface now occurs across the space where poor contact occurs, and this is shown by $(t_1' - t_i)$. In order to meet this condition, t_1 must be lowered to t_1' with a net decrease in the over-all rate process, since $(t_1' - t_i)/B < (t_1 - t_i)/B$.

The adverse effect of poor contact on the drying rate may be substantially offset if the retaining medium is made of a material transparent to radiant energy, and if radiant energy of the proper wave length is used as the source of heat. In this case, heat will continue to flow to the frozen solid even though poor contact occurs, since radiation does not depend on a solid medium for transmission, and another term, q_3, will be included in Equation (2) to account for radiation. If q_1 and q_3 are considered large compared with q_2, the following expression can be written for q when radiant heat transfer is used:

$$q = k_s A_1 \left(\frac{dt}{dx}\right)_i + AI \qquad (9)$$

where I is the intensity of radiation, B.t.u./(hr.)(sq.ft.) falling on the entire area A of the frozen solid. Thus, even though A_1 should go to zero, the term AI would remain effective so that the decrease in q would not be nearly so serious as in straight conduction drying expressed by Equation (6). Further, if the radiant energy penetrates the frozen material, even a small amount, this penetration in depth will produce a marked increase in drying rate.

3. Characteristics of Radiant Freeze Drying. Any body at an elevated temperature may be a source of radiant energy. The quantity of energy emitted by a black body is proportional to the fourth power of the absolute temperature as stated by the Stefan-Boltzmann law:

$$W_B = \sigma T^4 \qquad (10)$$

where

W_B = total radiant energy emitted by a black body, energy/unit area

T = absolute temperature

σ = constant

Planck's law gives the familiar relationship between the temperature of a black body and the intensity of the radiant energy emitted at each wave length, thus:

$$W_{B\lambda} = \frac{C_1 \lambda^{-5}}{e^{\frac{C_2}{\lambda T}} - 1} \qquad (11)$$

where $W_{B\lambda}$ = intensity of radiation at wave length λ. Figure 4 shows typical curves based on Equation (11), and they indicate that raising the temperature of a black body raises the peak intensity and shifts the total energy emitted toward shorter wave lengths. The product of the temperature and wave length at maximum intensity is a constant according to Wien's Law:

$$\lambda_m T = K \qquad (12)$$

Of greater interest is the per cent of the total energy that is emitted up to any given wave length. This may be calculated by integrating Planck's law from 0 to a given wave length, λ, and dividing the result by the total energy obtained by integration of Equation (11) from 0 to ∞. The values of the per cent of total energy between 0 and any wave length λ have been reported and tabulated by Lowan and Blanch (12). Figure 5 shows curves of their data for temperatures ranging from 200 to 2000° C.

When radiant heat is used in freeze drying it may be directed toward either the bottom or the top surface of the frozen solid. However, if the radiant energy is received at the exposed or drying surface, dry material will be exposed directly to the radiant energy for virtually the entire drying cycle and consequently may become overheated and degraded. On the other hand, if the radiant energy is applied through a transparent retaining medium, the solid in contact with the medium remains frozen while energy penetrates the frozen solid in depth, and sublimation occurs from the opposite or exposed surface. Beer's law gives the amount

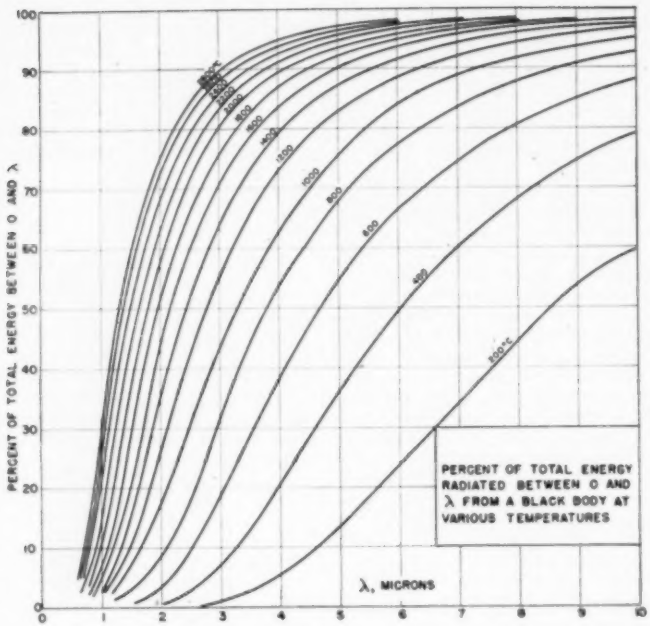
PERCENT OF TOTAL ENERGY BETWEEN O AND λ
λ, MICRONS
PERCENT OF TOTAL ENERGY RADIATED BETWEEN O AND λ FROM A BLACK BODY AT VARIOUS TEMPERATURES
1200°C
800
600
400°C

Fig. 5.

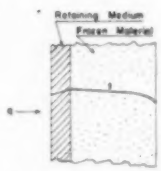

Fig. 6. Temperature gradient in frozen material for radiant heating with 100 per cent transparent screen.

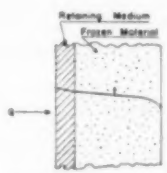

Fig. 7. Temperature gradient in frozen material for radiant heating with semi-transparent screen.

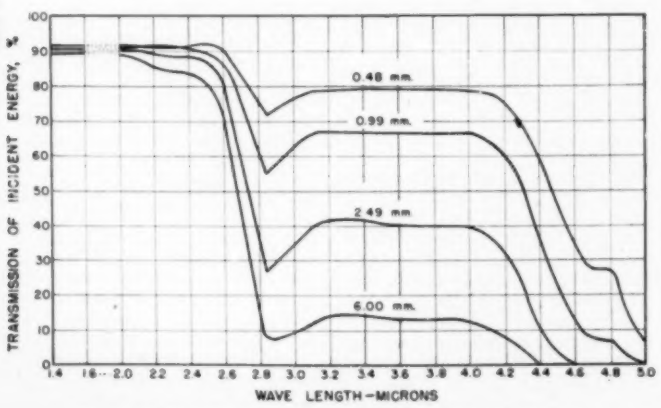

Fig. 8a. Radiant energy transmission characteristics of alkali resistant glass.

of radiant energy absorbed at any depth in a medium through which radiation penetrates. It may be expressed by

$$I = I_o(1 - e^{-ax}) \qquad (13)$$

where

a = the absorption or extinction coefficient
x = distance of penetration into the medium
I_o = the intensity at $x = 0$
I = energy absorbed up to x

Values of a are usually specified for a single wave length. In practice, however, essentially all wave lengths will be involved and hence a will vary with the depth of penetration.

If the container is completely transparent to the radiant energy the temperature gradients may approximate those shown in Figure 6. Since the container does not absorb energy it will be cooler than the material and heat will actually be conducted from the frozen solid to the container.

However, any material with 100 per cent transmission in the infrared region is not usually suited to commercial use (sodium chloride is such a material) so there will be some absorption and heating of the container. The probable temperature distribution in this case is shown in Figure 7. The gradient is not as steep as for conduction drying, yet a greater quantity of heat can be transferred because energy is being absorbed in depth.

Glass was used as a retaining medium in early studies with radiant energy (*10*). However, it absorbs very strongly at 2.5μ and completely above 3.5μ. Certain plastics have better transmission properties than glass in the infrared region. Radiant energy transmission curves for glass, Kel-F,* Teflon,† and polythene‡ are shown in Figures 8a and 8b. Curve 8a was furnished by the Corning Glass Works, and the curves in 8b by R. F. Colton (*3*). The three polymerized-ethylene-type plastics show obvious superior transmission characteristics over glass in the 2- to 7-μ range. By means of these curves it is possible to select the proper radiant source temperature to obtain a maximum amount of energy transmission.

In order to present a more significant picture of the transmission characteristics, the curve for energy distribution from a black body at 1200° C. was compared with the curves for the per cent transmission of radiant energy by glass, water, polythene, and Kel-F as shown in Figures 9-12. These curves aid in

* Polymerized trifluoromonochlorethylene made by M. W. Kellogg Co.

† Tetrafluorethylene resin made by Du Pont Co.

‡ Polymerized ethylene.

visualizing the percentage energy absorbed by these materials at those wavelengths where high absorptivity occurs.

The ability of materials to absorb radiant energy of a given wave length more strongly than other wave lengths is a familiar phenomenon and the basis for infrared spectroscopy as an analytical tool. Barnes et al (*1*) have compiled 363 curves showing the per cent transmission as a function of wave length from 5 to 12μ. A recent paper by Colthup (*2a*) reports a study of the absorption properties of a number of materials.

The effect of the source temperature, i.e., the effect of wave-length distribution, on the absorptivity of radiant energy by water was reported by Manders (*13*) and his results are reproduced in Figure 13. This figure shows that as the source temperature decreases, i.e., the per cent of energy in the long wave lengths increases, the per cent of total energy absorbed is increased. This implies the importance of selecting the source temperature compatible with the transmission properties of the retaining medium and the absorption properties of the frozen solid.

4. Mechanism of Radiant Freeze Drying. One method of visualizing the process of radiant freeze drying is to develop a picture of the temperature gradients occurring in a material during radiant freeze drying. To do this, a heat balance may be written over a small element of frozen solid, assuming a quasistationary process, i.e., the rate of retreat of the zone of sublimation is slow. Thus, with reference to Figure 14, the following steady-state heat balance over the thickness dx may be written

$$k_s \frac{d^2t}{dx^2} = -I_o \alpha e^{-\alpha x} \qquad (14)$$

where I_o is the energy of radiation incident on the frozen solid at $x = 0$. The boundary conditions for Equation (14) are:

1. At $x = 0$, $t = t_i$; where t_i = the interface temperature.
2. At $x = x_1$, $t = t_1$ and $-k_s \left(\frac{dt}{dx}\right) = I_o (1 - e^{-\alpha x})$.

Equation (14) can be integrated directly, twice, and after integration and substitution of the above boundary conditions, the following equation may be written to express the temperature at any position in the frozen solid:

$$t = t_i - \frac{I_o}{k_s \alpha} (e^{-\alpha x} + \alpha x - 1) \qquad (15)$$

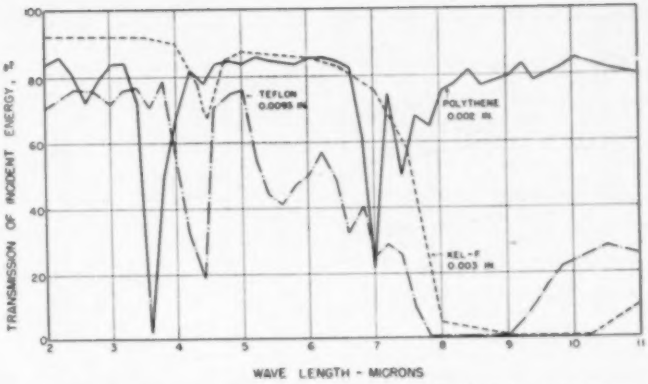

Fig. 8b. Radiant energy transmission characteristics of Teflon, polyethylene and Kel-F.

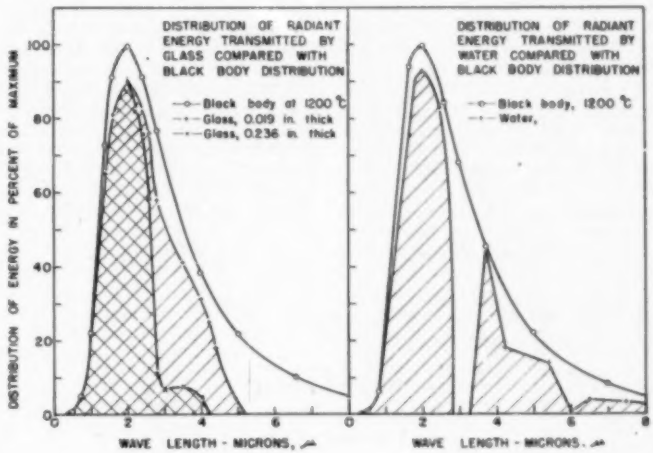
DISTRIBUTION OF ENERGY IN PERCENT OF MAXIMUM
DISTRIBUTION OF RADIANT ENERGY TRANSMITTED BY GLASS COMPARED WITH BLACK BODY DISTRIBUTION
Black body at 1200 °C
Glass, 0.019 in. thick
Glass, 0.236 in. thick
WAVE LENGTH - MICRONS, μ
DISTRIBUTION OF RADIANT ENERGY TRANSMITTED BY WATER COMPARED WITH BLACK BODY DISTRIBUTION
Black body, 1200 °C
Water,
WAVE LENGTH - MICRONS, μ

Fig. 9. Fig. 10.

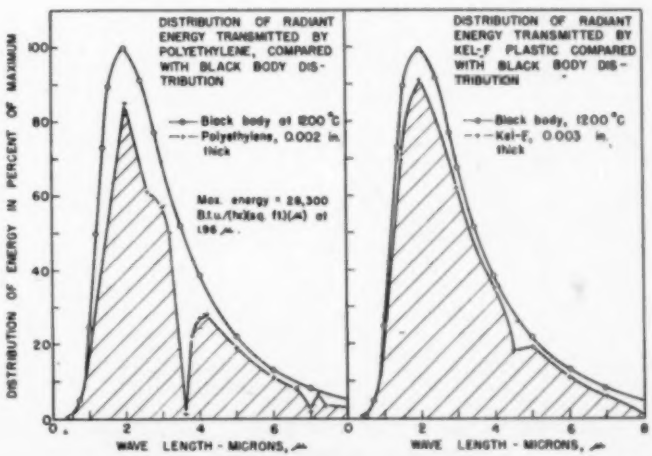
DISTRIBUTION OF ENERGY IN PERCENT OF MAXIMUM
DISTRIBUTION OF RADIANT ENERGY TRANSMITTED BY POLYETHYLENE, COMPARED WITH BLACK BODY DISTRIBUTION
Black body at 1200 °C
Polyethylene, 0.002 in. thick
Max. energy = 29,300 B.t.u./(hr)(sq. ft)(μ) at 1.96 μ.
WAVE LENGTH - MICRONS, μ
DISTRIBUTION OF RADIANT ENERGY TRANSMITTED BY KEL-F PLASTIC COMPARED WITH BLACK BODY DISTRIBUTION
Black body, 1200 °C
Kel-F, 0.003 in. thick
WAVE LENGTH - MICRONS, μ

Fig. 11. Fig. 12.

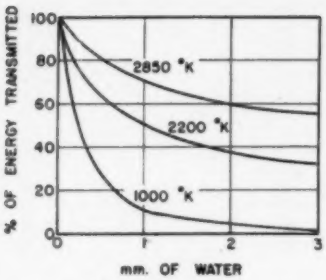

Fig. 13. Absorption of radiant energy by water (13).

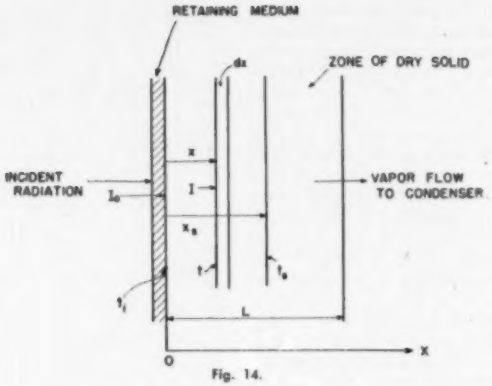

Fig. 14.

Equation (15) reduces to the case of pure conduction for $a \rightarrow \infty$, i.e., when the radiant energy is completely absorbed on the surface of the material. When $a = 0$, radiant energy is transmitted without absorption. In this case Equation (15) reduces to $t = t_i$.

Curves of $(t_i - t)$ vs. x based on Equation (15) have been plotted in Figure 15 for the arbitrary condition of $I_o = 500$ w./sq.ft., $k_s = 1.0$ B.t.u./(hr.)(° F.)(ft.) with a as a parameter. These curves show that when radiant energy is transmitted and absorbed the temperature gradients in the material are less steep than in the case of pure conduction. Thus, an over-all temperature drop of 8° F. is attained in a distance of only 0.055 in. for conduction, while with radiation and an average a of 100, a drop of 8° F. occurs over a distance of about 0.14 in. It should be noted that the values of a should be considered as average values, since a is presumably a function of depth due to the fact energy of all wave lengths is involved. As an example, values of a for ice for various wave-length ranges are tabulated as shown in Table A (8):

TABLE A.—VARIATION OF a FOR ICE WITH WAVE LENGTH

Wave Length Range, μ	a, 1/ft.
0-2	0
2-3	10,000
3-4	1,000
4-10	100

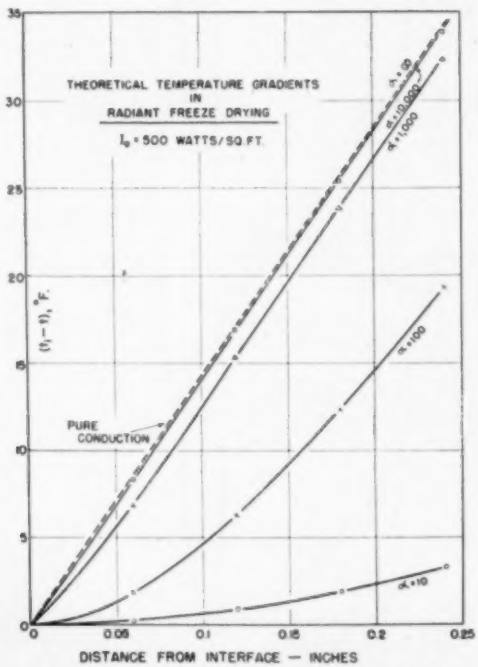

Fig. 15. Temperature gradients calculated from Equation (15).

a as used in the equations should probably be averaged according to the percentage of total energy occurring in the various wave bands. Fox and Martin (8) have reported the infrared absorption spectra for ice and water.

In the most general case of freeze drying, the drying rate will be a function of both heat and mass transfer. Thus, a rigorous treatment of the drying mechanism must include equations to account for the rate of mass or vapor transfer through the porous solid, as well as heat-transfer equations to account for the rate of heat flow to the plane of sublimation. As in other processes, however, special cases may be encountered such as heat-transfer controlling or mass-transfer controlling wherein simplified treatments are possible. Thus, one simple treatment for heat-transfer controlling would be to assume that all the heat being conducted into the plane of evaporation is used for sublimation, corresponding to boundary condition 2, above. In this case the rate of retreat of the plane of sublimation may be written as

$$-W_o \rho \lambda_s \frac{dx_s}{d\theta} = I_o(1 - e^{-ax_s}) \qquad (16)$$

where W_o = concentration of ice in undried zone, lb./lb. of dry solid, and ρ = bulk density of dry solid, lb. In the case of a perfectly transparent retaining medium, Equation (16) may be integrated to give

$$\frac{e^{L(W/W_o)} - 1}{e^{aL} - 1} = e^{-Ia\theta/\lambda_s W_o \rho} \qquad (17)$$

or

$$\frac{W}{W_o} = \frac{1}{aL} \log \left[1 + (e^{aL} - 1)\, e^{-I_{ab}\theta/\lambda W_o p}\right] \tag{18}$$

When aL is small, Equation (17) simplifies to

$$\frac{W}{W_o} = e^{-I_{ab}\theta/\lambda W_o p} \tag{19}$$

It should be recognized that Equations (17) to (19) represent an extreme simplification of the freeze-drying process and will hold only when the material being dried is quite porous and the rate of mass transfer through the material is high.

Experimental Equipment and Procedure

1. *Description of Equipment and Methods of Measurement.* The experimental equipment used to obtain drying rates is shown in Figure 16. The vacuum drying chamber was a 6-in. Pyrex glass cylinder resting on a stainless steel base. A brass condenser for condensing water vapor as ice closed the cylinder at the top. A brass coil running through the condenser connected the chamber to a ¼ hp. Cenco Hyvac pump. The condenser was cooled by means of a dry ice-acetone mixture, and the water vapor liberated in the system condensed as ice or snow on the brass surface above the sample.

In tests with radiation, the sample support consisted of a nickel-plated copper wire screen laminated with Kel-F plastic sheets. The copper wires were 0.01 in. in diameter and occupied about 42% of the cross-sectional area. In runs 1 to 12, rock salt was used as a filler in the screen with a coating of polythene over a copper screen. For the conduction tests, the sample support was a copper plate, 1/32 in. thick, painted black on the underside. A No. 24 copper-constantan thermocouple was soldered in the center of the plate to measure its temperature. No. 30 copper-constantan thermocouples were used to measure the sample temperature.

The screen and frozen sample were suspended from a calibrated phosphor bronze spring mounted in the vacuum chamber. A traveling microscope mounted outside the chamber on an accurate micrometer scale was used to measure the deflection of the spring as drying progressed, and thus moisture content vs. time data was obtained.

The radiant heater consisted of four circuits of 0.010-in. Nichrome wires. Each circuit was 12 in. long. A 1/6 rev./min. synchronous motor operated four cams which cycled the heating circuits to prevent concentration of energy and to simulate the movement of a continuous belt. No direct measurement of the wire temperatures was made. However, approximations of wire temperatures were estimated from the power input. Since the power input was low, direct current was used in order to measure the power accurately by means of a 1.0 amp. d.c. ammeter, and a 0-30-v. d.c. voltmeter. Different wire temperatures at a constant power input were obtained by using wires of different diameter.

A pirani gage was used to measure the pressure at the sample level and a modified McLeod gage measured the pressure at the condenser exit.

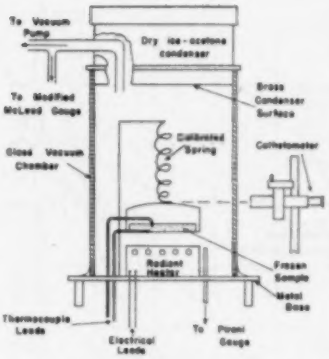

Fig. 16. Diagram of experimental radiant freeze dryer.

2. *Experimental Procedure.* The sample to be dried was frozen rapidly in a dry-ice freezer on the screen or plate used for support. After the sample was frozen and cooled to about —70° C. it was placed in the vacuum chamber and the pump started.

When the pressure became less than 500 μ, the heater was turned on. The pressure, power and spring reading were recorded every five minutes. Thermocouples in the sample were read at time intervals ranging from 15 sec. to 5 min. depending on how rapidly the sample temperature was changing.

The final moisture content was determined by heating the sample in an oven at 110° C. until it reached constant weight.

In runs 18, 23, 24, 25, and 27, the power input was constant throughout the entire run. The heat input for the rest of the runs was the maximum possible without causing melting at the interface or blowing the product off the tray or overheating the product when dry. For this reason, variations in energy input are indicated in these runs.

The test materials used in all runs were commercial organic dyes.

3. *Accuracy of Measurements.* The spring and cathetometer were calibrated under the conditions that existed during the drying runs. In a calibration in air, the thermocouples fastened to the sample were found to have a constant effect on the spring elongations. The weight measurements were believed to be accurate to about 5%.

The thermocouples were checked at the solid carbon dioxide sublimation point.

4. *Radiation Absorption Measurements.* The radiant-energy transmission ability of the Kel-F-nickel-plated copper screen support was observed qualitatively. A thermocouple was mounted on a piece of aluminum foil about ½ in. in diameter. This target was placed approximately one inch from the heating elements. Temperatures were

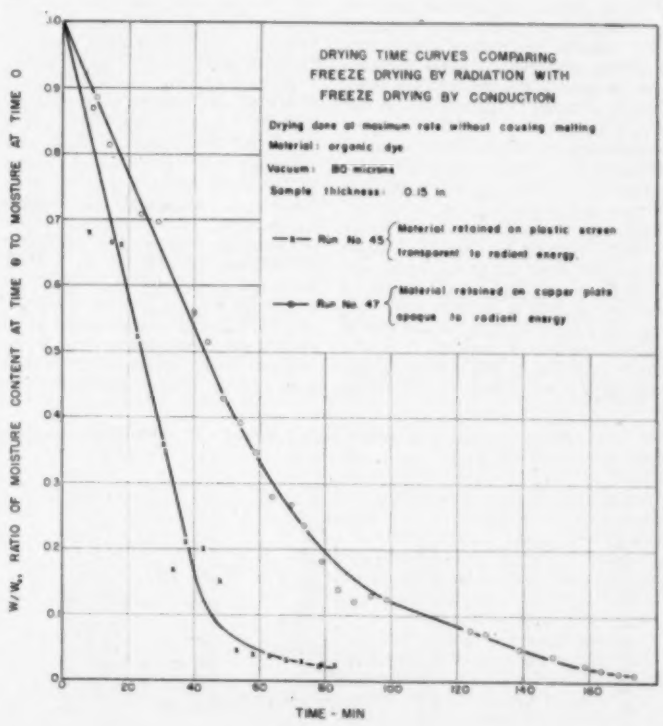

Fig. 17.

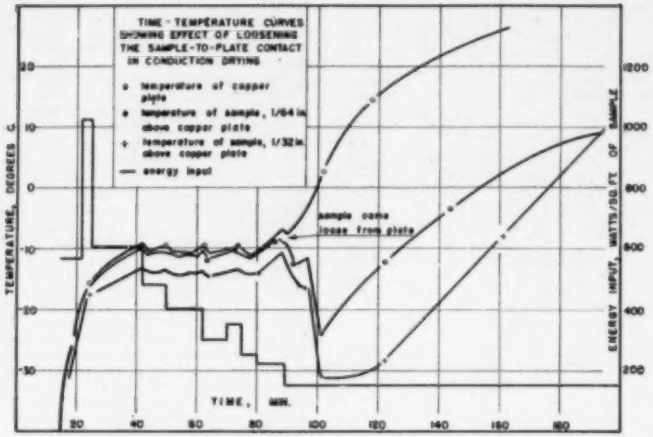

Fig. 18.

recorded every 15 sec. after the power was turned on. Measurements were then taken with the Kel-F-nickel-plated copper screen and the copper plate between the heater and target.

Discussion of Results

1. *Comparison of Conduction and Radiation.* The capacity figures in Table 1 compare the rates of radiation and conduction freeze drying. The average capacity for radiant drying was 0.134 lb./(hr.)(sq.ft.), while for conduction heating the capacity was 0.077 lb./(hr.)(sq.ft.). Figure 17 is a plot of the data for runs 45 and 47 to compare radiant freeze drying with conduction freeze drying. It is evident from this comparison that it took about twice as long to dry to 4% moisture by conduction freeze drying than by radiant freeze drying. These curves also show that in conduction freeze drying the drying rate falls off more rapidly near the end of the process than in radiant freeze drying. This is due to the benefit of energy penetration into the sample. It is also to be noted that in both methods a constant drying period occurs. For radiant drying, run 45, the constant rate lasted until about 83% of the ice had been sublimed, while for conduction drying it lasted only until about 60% of the ice was sublimed. Thus, with radiant energy the terminal drying period is not as large a fraction of the total cycle as in conduction drying. The constant rate also represents the maximum rate of ice sublimation and hence its magnitude is of importance in the design of the vapor condensers for freeze dryers. Thus, the maximum rate of sublimation in run 45 was 3.06 lb. water/(lb. dry solid)(hr.) and this rate would have to be handled by refrigerated vapor condensers or other vapor-removal systems. With rates of sublimation of this magnitude, it is probable that the simplifying assumption (*5a*), namely, that the resistance to heat flow is unaffected by thickness of the ice on the refrigerated condenser, is invalid, and that design data on heat-transfer coefficients and thermal conductivities of ice on refrigerated condensers must be determined for the proper design of these units. At low rates of sublimation, the ice layer on refrigerated condensers may cease to be a controlling factor, but this is a limiting or equilibrium condition and cannot be generalized for all rates of condensation.

For efficient drying by conduction only, as discussed previously, it is necessary to have good adherence between the sample and the heating surface. Figure 18 shows the variation with time of the temperature of the sample and heating surface when good adherence exists and also after the material has come loose. The data show that after the bond between sample and heating surface had been broken, it was necessary to cut the power almost to zero to keep the copper plate below 0° C., i.e., to prevent melting at the interface. Because of the power cut back the temperatures were lowered with the result that the rate of heat transfer was decreased considerably. This is in accordance with the earlier discussion based on Figure 3.

Since some of the radiant energy was absorbed by the plastic screen, heat was supplied by conduction as well as by radiation in radiant drying. Thus, to make a good comparison between conduction and radiation drying, it was necessary to restrict the comparison to those runs where a good sample to plate bond was maintained during the drying cycle. Even in a radiant freeze-drying test, the drying rate fell off when the sample broke loose from the screen, thus indicating that a good bond with the retaining medium is equally desirable in radiant freeze drying.

2. *Effect of Initial Ice Concentration.* It was believed that, because of the high absorptive capacity of ice for radiant energy, at higher ice concentrations higher rates of heat flow could be obtained, and hence higher drying rates. To test this, two runs were made at two substantially different initial moisture contents. The drying-time curves and data for the runs are shown in Figure 19. It is apparent that much higher drying rates or rates of sublimation

TABLE 1.—DRYING CAPACITY FOR RADIANT AND CONDUCTION FREEZE DRYING OF AN ORGANIC DYE

Run No.	Water cont. (wet basis) Initial	Final	Vacuum μ	Dry Thickness, in.	Energy conc. w./sq.ft.	Approx. Source Temp., °F.	Drying Time to 4%, min's	Capacity, lb.prod./(hr.)(sq.ft.)
18	71	...	240-75	0.22	250	1300	...	...
19	71	...	300-70	0.21	560-135	1660-1060	...	...
23	71	3.2	200-35	0.13	560	1830	93	0.13
24	71	3.8	200-75	0.16	560	1700	105	0.13
25	71	2.1	450	0.24	560	1700	178	0.11
27	75	3.9	250-50	0.21	560	1700	116	0.09
*32	71	2.9	200-50	0.15	1050-475	2100-1600	180	0.067
33	71	4.9	200-50	0.15	1050-220	2100-1280	...	...
35	71	3.2	200-50	0.15	1050-160	2100-1150	86	0.15
36	71	2.3	175-20	0.12	1050-160	2100-1150	108	0.12
*38	71	2.1	350-220	0.12	1050-160	2100-1150	...	...
40	71	6.3	175-20	0.15	1050-80	2100-880	...	...
*41	71	2.1	200-60	0.16	610-150	1750-1150	162	0.082
43	71	2.0	200-20	0.15	1050-160	2100-780	109	0.12
45	71	3.3	150-25	0.15	740-260	1880-1340	95	0.15
46	71	1.9	200-20	0.14	530-140	1700-1150	94	0.14
*47	71	2.4	150-25	0.15	940-140	2000-1150	165	0.082

* Conduction runs.
NOTE: The approximate freezing point of the sample was —2° C.

can be obtained with higher initial ice concentrations. However, when the results were interpreted in terms of drying capacity, it was found that no essential difference existed. Thus, for the low moisture content the capacity for drying to the same final moisture content was 0.13 lb. product/(sq.ft.)(hr.) for a drying time of 6 hr., while at the higher moisture content the capacity was 0.124 for a drying time of only 2.67 hr. Similar results were obtained in other tests on the effect of initial ice content. Thus, any benefits to be expected from higher initial ice concentrations would have to be found in product quality and improved physical properties. For example, a dry product from a high moisture content material might have improved solubility. However, any product advantages would have to offset the disadvantages of greater freezing capacity requirements, higher evaporation loads, higher power requirements, and larger condenser and refrigeration units.

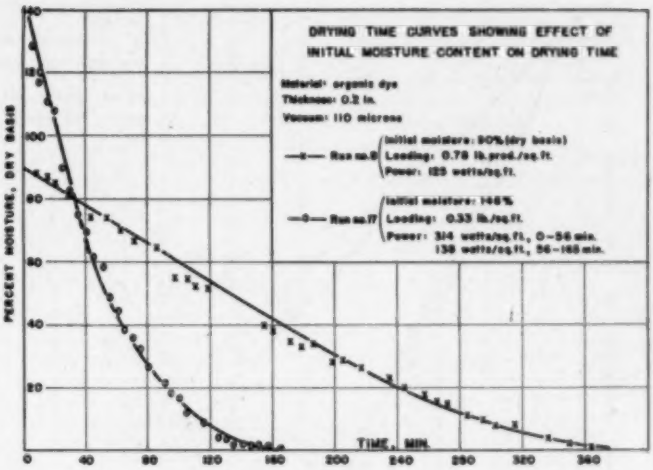

Fig. 19.

3. *Effect of Sample Thickness.* Two runs were made to observe the effect of thickness on radiant freeze drying. The drying-time data for these runs are plotted in Figure 20. These preliminary results indicated that for a 42% increase in loading or approximately a 50% increase in thickness the drying time was increased about 100%. In these particular runs, the drying capacity to 4% moisture for the light loading was 0.16 lb. product/(hr.)(sq.ft.) and 0.113 for the heavier loading or about a 30% decrease. Thus, it appears that at the solids content used in this study an increase in loading may result in a lower drying capacity. It is to be noted that the vacuum in each test was not constant. An attempt to establish the effect of vacuum below 500μ showed that no appreciable effect could be detected.

4. *Effect of Energy Concentration and Source Temperatures.* A series of runs was made to study the effect of energy concentration on the drying time. Figure 21 shows the curves of W/W_o vs. time for these tests. As would be expected, the lower the energy concentration the longer the drying time. It should be observed further that when the energy concentration was reduced from its initial value to successive lower values, as in run 14, the drying time curve flattened out rapidly. This may be attributed to two factors: (1) reduction in energy, and (2) the change in wave-length distribution causing a change in per cent energy absorption by the sample and its support.

Figure 22 shows a plot of energy concentration vs. drying time to 2% for the runs in Figure 21. This relation is essentially linear over the range considered, and combines the effect of source temperature with energy concentration. A more significant relationship would be energy concentration at a constant source temperature vs. time.

5. *Penetration of Radiant Energy.* Figure 23 presents the results of two qualitative tests made to obtain experimental evidence of penetration of radiant energy into the frozen sample. One test was made with the Kel-F screen support and the other with the copper plate as the support, i.e., a conduction test. In both tests, after the power was shut off the sample was cooled by continued sublimation of the ice. The thermocouple in the sample dropped much more rapidly with the Kel-F screen support than with the copper plate. This was accepted as evidence that radiant energy had penetrated to the thermocouple. This result also implied that thermocouples in the samples during radiation drying tests might have measured a temperature greater than the actual sample temperature depending on the size of the couple, its absorptivity, and its intimacy of contact with the material.

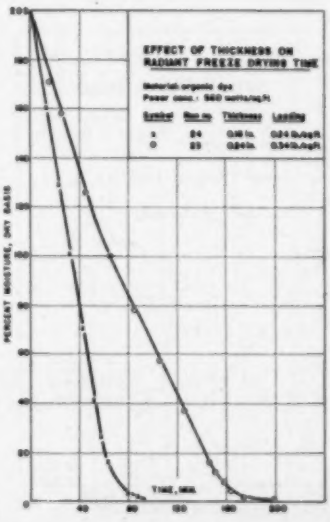

Fig. 20.

Similar results in the infrared drying of textiles have been reported by Wilhelm and Smith (*19*).

6. *Transmission of Energy by Plastic Screen.* With the radiating source at 1700° F., and the Kel-F screen in place without frozen material, time-temperature curves were obtained for a blackened aluminum foil target exposed to the face of the Kel-F screen on the opposite side of the radiant heater. These curves are plotted in Figure 24. With a vacuum of 50μ, convection effects were negligible so that the target received heat only by radiation from the wires and by re-radiation from the Kel-F screen, and lost energy by radiation to the condenser at −78° C. located about 6 in. above and behind the target.

When the Kel-F screen was placed between the heater and target, the screen transmitted most of the energy and reflected or absorbed the rest. As the screen absorbed energy, its temperature rose and it then reradiated energy to the target. However, since the time-temperature curves for the target with and without the screen interposed show similar rate-of-change characteristics, it seemed justifiable to conclude that a

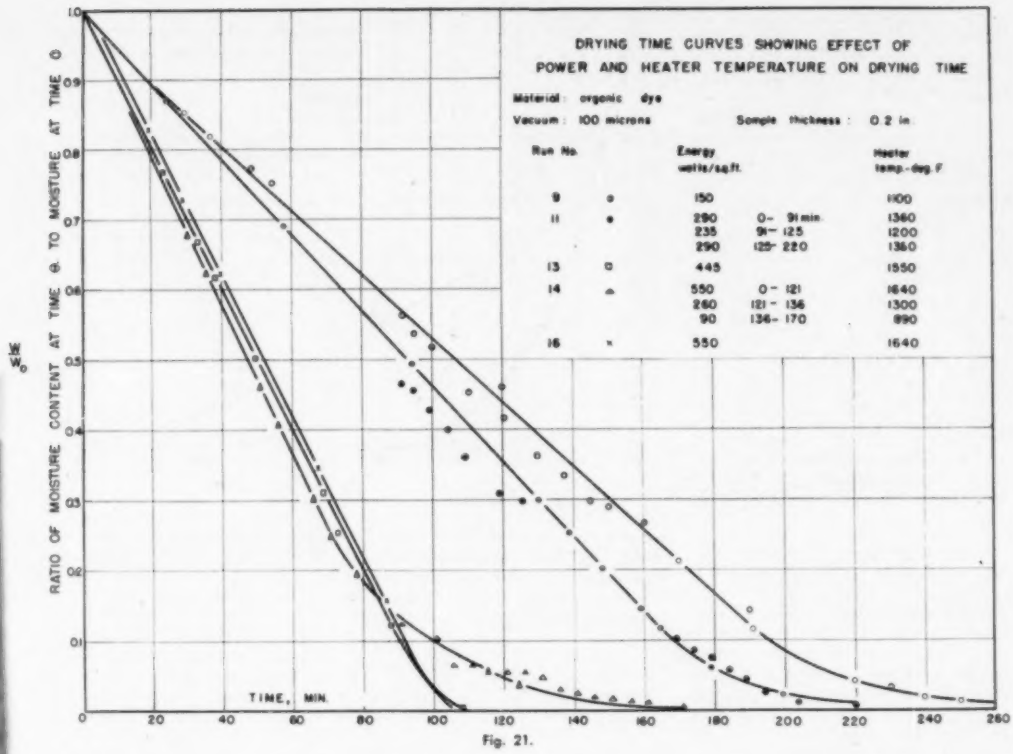
DRYING TIME CURVES SHOWING EFFECT OF
POWER AND HEATER TEMPERATURE ON DRYING TIME
Material: organic dye
Vacuum: 100 microns
Sample thickness: 0.2 in.
Run No. | Energy watts/sq.ft. | | Heater temp.-deg. F
9 | 150 | | 1100
11 | 290 | 0- 91 min. | 1360
235 | 91- 125 | 1200
290 | 125- 220 | 1360
13 | 445 | | 1550
14 | 550 | 0- 121 | 1640
260 | 121- 136 | 1300
90 | 136- 170 | 890
16 | 550 | | 1640
RATIO OF MOISTURE CONTENT AT TIME θ TO MOISTURE AT TIME 0
W/W0
TIME, MIN.

Fig. 21.

large fraction of the radiant energy was transmitted through the screen. No quantitative estimate was made from this test as to the actual fraction of energy transmitted. More precise data on penetration will be reported in another paper.

When a copper plate was placed between the target and heater, the plate temperature increased rapidly as it absorbed energy. Since the copper was opaque to energy of the wave lengths studied, any energy which reached the target came as reradiated energy from the plate. As a result, the target showed a rate of heating different from the case for the screen, as shown by the lower curve in Figure 24. This curve was actually an indication of the rate of heating of the copper plate, and is a typical unsteady-state heating curve, with an inflection point near zero time.

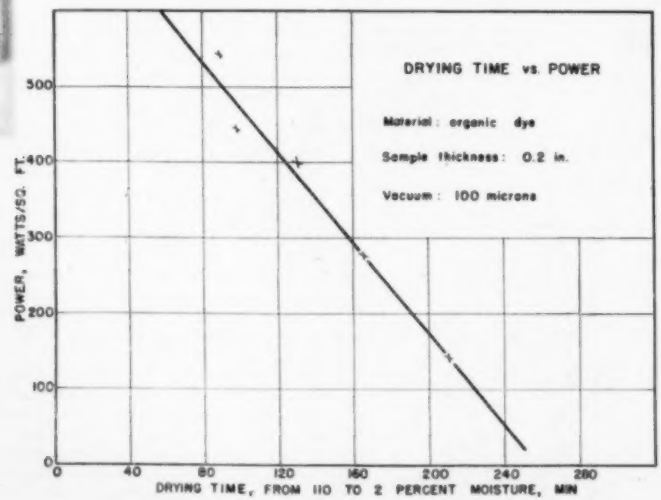
DRYING TIME vs. POWER
Material: organic dye
Sample thickness: 0.2 in.
Vacuum: 100 microns
POWER, WATTS/SQ. FT.
DRYING TIME, FROM 110 TO 2 PERCENT MOISTURE, MIN

Fig. 22.

Conclusions

Freeze drying with radiant energy can be more rapid than with conduction heating because of the penetration of radiation into the sample. Thus, the freeze-drying capacity for an organic dye was increased by 74% by virtue of the penetrating effect of radiant energy. This conclusion will not hold, however, whenever mass transfer rather than heat transfer is the controlling mechanism.

Drying rates are higher with higher percentage moisture contents, but the production capacity of dry product is not increased.

The drying rate is greatly influenced by the nature of the contact between the retaining medium and the frozen solid.

Poor contact greatly reduces the drying rate in both conduction and radiant freeze drying.

Increasing the sample thickness decreases the drying capacity for materials with solid contents of 30%.

Qualitative tests indicated that radiant energy definitely penetrated the frozen solid during drying.

Acknowledgment

The authors wish to acknowledge the Wisconsin Alumni Research Foundation and Proctor and Schwartz, Inc., for financial support. The authors are grateful to R. F. Colton of the Dry-Freeze Corp. for valuable suggestions, and for the contribution of unpublished data on radiant energy transmission.

Notation

A = area of sublimation, sq.ft.
A_1 = area in contact with retaining medium, sq.ft.
A_2 = area not in contact with retaining medium, sq.ft.
B = thickness of medium supporting frozen material, ft.
C_1, C_2 = constants in Planck's law, Eq. (11)
f_1 = fraction of total area of frozen material in contact with retaining medium
f_2 = fraction of total area of frozen material not in contact with retaining medium
h_i = film heat-transfer coefficient
I = intensity of radiation, energy/(unit area) (unit time)
k = thermal conductivity
K = Wien's law constant, Equation (12)
L = total thickness of dry solid
q = rate of heat flow
R_i = resistance to heat flow
t = temperature, ° F.
T = absolute temperature
x = distance into frozen solid
x_s = distance to plane of sublimation
W = lb. water/lb. dry solid at any time
W_o = lb. water/lb. dry solid initially
W_B = total radiant energy emitted by a black body
$W_{B\lambda}$ = radiant energy of wave length λ emitted by a black body

Greek Letters:

α = absorption coefficient, 1/length
λ = wave length, μ
λ_s = latent heat of sublimation, B.t.u./lb.
μ = microns
σ = constant in Stefan-Boltzmann law, Equation (10)
θ = time, hr.

Subscripts:

i refers to interface conditions
m refers to retaining medium and maximum wave length. Equation (12)
o refers to incident radiation
s refers to surface of sublimation or to solid-ice mixture
v refers to vapor space at interface

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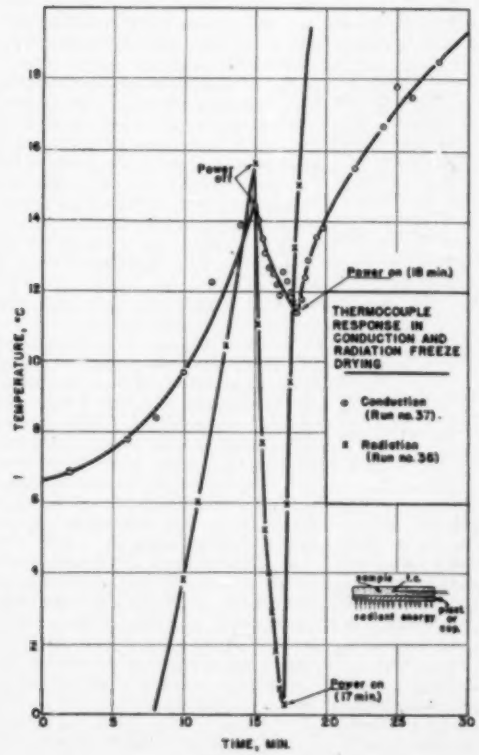

Fig. 23.

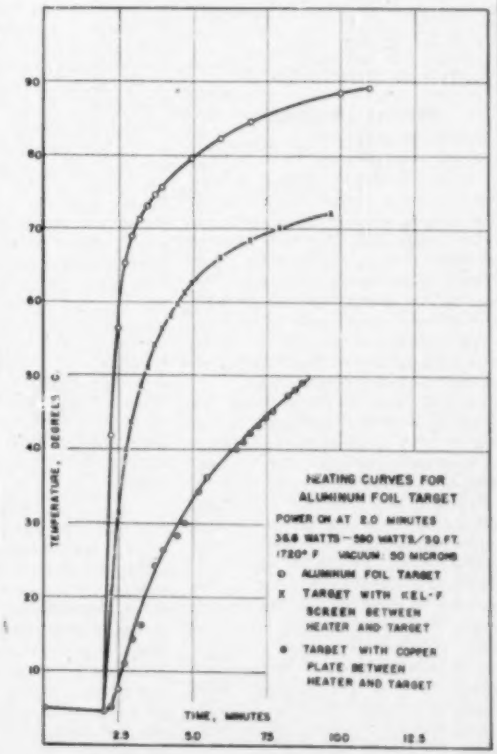
TEMPERATURE, DEGREES C
TIME, MINUTES
HEATING CURVES FOR ALUMINUM FOIL TARGET
POWER ON AT 2.0 MINUTES
368 WATTS – 580 WATTS/SQ.FT.
1720° F VACUUM: 50 MICRONS
o ALUMINUM FOIL TARGET
x TARGET WITH KEL-F SCREEN BETWEEN HEATER AND TARGET
• TARGET WITH COPPER PLATE BETWEEN HEATER AND TARGET

Fig. 24.

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Written Discussion

Earl W. Flosdorf (F. J. Stokes Machine Co., Philadelphia 20, Pa.): The introduction to this paper properly indicates that freeze drying is directed mostly at present toward the preservation of biologicals and other heat-sensitive materials. The paper reports on a preliminary experimental study using organic dyes as sample material for tests. To this extent caution must be exercised in interpretation of the data for applying it to the drying of labile biologicals and other heat-sensitive materials.

It is well known in freeze drying that the ice layer recedes gradually so that some is dried much before completion of drying the entire mass. Any heat absorbed by the first dried portion will not be dissipated by loss of heat of sublimation of moisture so that the temperature of the dried part can be raised to above a safe point and deterioration will result. In fact, this places a limitation on the maximum temperature of the heating medium which may be used in the so-called "conductance method" whereby with certain materials a much lower temperature of the heating source must be used than with others in order to prevent so-called "toasting" of the dried surface.

In results I have seen, it has not been possible to dry certain heat-sensitive materials like guinea pig complement and Brucella abortus vaccine using the high temperature source of radiant energy on which Zamzow and Marshall report without virtually complete loss of activity.

It should be pointed out that it is a misnomer to think of "conductance heating" as being entirely conductance. Thermal contact is seldom good enough, particularly when carrying out drying in a vacuum chamber. Much of the heat must be radiated through vacuum space even from a hot water source to the material being dried. To this extent there is no difference in principle in using wave lengths in or near the visible range. To establish that such high temperature radiant energy can produce faster drying of heat-sensitive biologicals without loss of potency it will be necessary to collect data using such heat-sensitive materials. As a control on so-called "conductance heating" data must be collected using the maximum heating fluid temperature permissible.

In fact, in the available data I have seen where heat-sensitive materials have been dried by both types of heating, the so-called "conductance method" produced equally fast if not faster results and with greater ease of control. However, this comparison should be made the subject of a more extensive and well-planned study.

To accomplish most rapid drying, the heat should be carried directly to the evaporating surface of the ice only, which is where it is being used. Until now with either high temperature radiant energy or with a high temperature heating fluid this has not been accomplished and therefore it is necessary to guard against overheating of the first dried portion of heat-sensitive materials. This means to avoid loss of biological activity when using either one of these two high temperature sources, most careful and delicate control is required, with lowering of temperature when approaching the terminal portion of the drying cycle. Accordingly, the preliminary data with organic dyes presented in the foregoing paper cannot be applied directly to drying heat-sensitive materials.

Discussion

F. B. Crist (Armour & Co., Chicago, Ill.): I notice that you use a colder surface temperature on your radiant elements. A better absorption by the product is obtained due to change possibly in the infrared band. It would seem then that while leaving the temperature low you could increase your radiant surface up to a certain optimum point to get a maximum radiation into the product. But what is the limiting factor—the temperature of the product or when you have reached your limit of speed to dry the material? In other words, when you increase the radiation on your product, what is the limiting factor on how fast you can dry it? Is it the temperature of the product?

W. H. Zamzow: It's the temperature of the material. If you want to keep it frozen you can't heat it above its freezing point—you have to stay a certain range below its freezing point.

F. B. Crist: Assuming then that you can draw the moisture away fast enough to maintain your low vacuum, that would tend to keep the material below a certain temperature. Has this process been speeded up as much as possible, or is there still a possibility of having more efficiency for adding energy and getting faster drying?

W. H. Zamzow: Well, there is probably some room for that. One is always limited on the maximum temperature he can get for source of radiant energy.

D. E. Severson (University of N. Dakota, Grand Forks, N.D.): In freeze drying, where the zone of sublimation recedes from the surface continuously, why is there a constant rate period?

W. H. Zamzow: Generally in freeze drying we use materials with a low solid content—sometimes less than 1% solids and it can be up to 50% solids. In the case of a low per cent of solids there can be little resistance to diffusion of the water vapor away from the zone of sublimation.

E. E. Wynkoop (Stokes Machine Co., Philadelphia, Pa.): Presumably the heat enters the material being dried at a high temperature level since it is generated from high temperature source. Would not the toasting, you might say, be detrimental to the biological potency of some of the more sensitive materials such as guinea pig complement for which you have presented no actual data?

W. H. Zamzow: I don't know what you mean by toasting.

E. E. Wynkoop: High temperature can be tolerated only for a short time, I take it, otherwise you have to shut off the heat source. You have a high temperature for a relatively short time to give a small quantity of heat to produce evaporation. That high temperature you would expect to be detrimental to the first dried portions such as edges and bottom when certain products are extremely heat-sensitive.

W. H. Zamzow: The heater has to be placed properly so that there is no overheating. You can get your high temperature without having a high power input by going through the right size heater. We have dried a guinea pig complement successfully, and have had no trouble with the toasting.

(Presented at Minneapolis (Minn.) Meeting.)

APPLICATIONS OF FLUID MECHANICS AND SIMILITUDE TO SCALE-UP PROBLEMS

PART I

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A brief review of the principles of dynamic similitude is given. Basic concepts of fluid mechanics are used to develop relations between fluid motion, equipment size, and fluid properties that may apply to chemical engineering work. A general method is given whereby the requirements for dynamic similitude for any flowing system can be determined. Examples are given showing how these principles can be used in pilot plant models to obtain scale-up data for operations involving resistance to fluid flow, discharge of liquids from tanks, blending of liquids by a mixer, control of forced vortexes, dissolving of solids during mixing, and absorption and desorption of gases in moving liquids. Suggestions are made for applying the principles to any type of operation involving mass transfer in a liquid, and to other flow operations such as fluidized systems and suspensions.

THIRTY-FIVE years ago Lord Rayleigh wrote (*12*), "I have often been impressed by the scanty attention paid even by original workers in physics to the great principle of similitude." This author feels impelled today to say, "I have often been impressed by the scanty attention paid by chemical engineers to the great principle of similitude."

Pilot plant studies are frequently initiated for the purpose of obtaining reaction rate and equipment performance data so that large scale equipment can be sized to give desired operational capacity. This discussion deals with processes wherein liquid motion is involved and where the reaction rate is controlled in full or in part by a concentration distribution in the liquid phase. If data obtained on a small-sized operation of this type are to be applicable to large scale design it is essential to know the effect of size on liquid motion and on the distribution of concentration. Unless the concentration pattern of the pilot can be achieved on the large scale operation, it will not be possible to duplicate the rate of action at the same temperature. And, unless the concentration pattern can be related to liquid motion, it will not be possible to predict the rate of reaction for different motion patterns.

It is intended here to call attention to principles of fluid mechanics and similitude which must be considered in the projection of experimental chemical engineering programs and for the evaluation of pilot plant data if such information is to become the basis for scale-up.

Some of the process operations involving liquid motion where size may have a significant effect on reaction rate are: mixing, liquid-liquid extraction, absorption, and desorption of gases in liquids, solution of solids, distillation, and heat transfer. In general, any mass- or heat-transfer operation involving a reaction at an interface is dependent on fluid motion and may therefore be dependent upon the size and shape of the system.

To illustrate the connection between fluid mechanics and process operations, the reader can consider, for example, the desorption of a gas from a liquid under such conditions that the rate is primarily a function of the rate at which the gas molecules move through the liquid to the liquid-gas interface. This is a case ordinarily referred to as one in which the "liquid film coefficient" is said to be controlling.

When the liquid with dissolved gas is in a quiet unagitated pool the rate at which gas molecules leave the interface and are desorbed depends upon the transport of molecules to the interface, and such transport is known as molecular diffusivity and natural convection. Diffusion coefficients for such operations have been evaluated for many substances. If forces are exerted on the liquid to produce fluid motion, then material will be transported to the interface by forced convection as well as by natural convection. When the liquid is agitated by a mixing impeller or by flowing through a bed of packing, the transport of molecules to the interface will be affected by the liquid motion. It would, therefore, be expected that the rate of desorption of the gas would be a function of the liquid motion as well as of its specific diffusivity. And, it follows, that evaluation of this effect can be made in terms of the liquid film coefficient of mass transfer, since the postulated "film theory" is convenient for handling transfer of material by convection. Accordingly, a liquid film coeffi-

TABLE 1. FORCE CHARACTERISTICS IN FORCE, LENGTH, TIME DIMENSIONS.

FLUID PROPERTY	SYMBOL & FORCE DIMENSION	KINEMATIC NOTATION force / mass	KINEMATIC DIMENSION	DIMENSIONLESS NUMBER		
				NAME	GROUP	GROUP
$F = Ma$	$\rho = \frac{FT^2}{L^4}$	$a = \frac{F}{M}$	$\frac{L}{T^2}$	INERTIA	$\frac{FT^2}{\rho L^4}$	$\frac{F}{\rho u^2 L^2}$
SPECIFIC WEIGHT (gravity)	$\gamma = \frac{F}{L^3}$	$g = \frac{\gamma}{\rho}$	$\frac{L}{T^2}$	FROUDE	$\frac{L}{T^2 g}$	$\frac{u^2}{Lg}$
VISCOSITY	$\mu = \frac{FT}{L^2}$	$\nu = \frac{\mu}{\rho}$	$\frac{L^2}{T}$	REYNOLDS	$\frac{L^2}{T\nu}$	$\frac{Lu}{\nu}$
SURFACE TENSION	$\sigma = \frac{F}{L}$	$\omega = \frac{\sigma}{\rho}$	$\frac{L^3}{T^2}$	WEBER	$\frac{L^3}{T^2\omega}$	$\frac{Lu^2}{\omega}$
MODULUS OF ELASTICITY	$K_e = \frac{F}{L^2}$	$e = \frac{K}{\rho}$	$\frac{L^2}{T^2}$	CAUCHY	$\frac{L^2}{T^2 e}$	$\frac{u^2}{e}$

u = VELOCITY = L/T

cient is a function of fluid motion and therefore the same fluid motion would be necessary in two sizes of equipment in order to achieve the same film coefficient and the same rate of desorption.

If fluid motion is imposed on the liquid behind the reaction interface, there will result a definite pattern of flow and of concentration of molecules. Therefore, it is essential to understand the effect of all forces and boundary conditions on the liquid flow pattern, because these conditions will affect the distribution, or concentration, and the transport of the molecules.

It has been noted by Hutchinson and Sherwood (*9*) and by others, that liquid film coefficients in absorption processes are indeed dependent upon agitation and liquid motion. Other processes just referred to have also been observed to depend on agitation, but few attempts have so far been made to relate these phenomena in a comprehensive way to the mechanics of fluid motion (*15*). The application of the principles of similitude in fluid motion appear to have wide application to chemical processing. These principles have been used extensively in heat-transfer and certain mass-transfer operations (particularly in the gaseous phase), but little has been done to prove their value in planning small scale process experiments where liquid motion is important, and in interpreting results for the design of larger equipment to accomplish equivalent results. In the field of mixing, for example, many pilot plant studies have been completely useless for scale-up purposes because of neglect to consider some of the parameters of fluid motion.

If it is known that a chemical process rate is dependent on fluid motion behind an interface or in a flowing stream, it should then be possible to reproduce the same chemical rate in a small experimental model or in a large unit provided that dynamic similarity of flow can be achieved. The condition of dynamic similarity is necessary rather than geometric or kinematic similarity alone, because forces are required to move the mass of the substance in the manner desired. Unless dynamic similarity can be achieved or closely approximated, it will not be possible to reproduce results on any other scale if all other operating variables such as pressure and temperature are held constant.

Similitude and Forces

The forces and directions of flow at various points in liquids moving in mixing vessels, packed towers and other processing equipment are difficult to evaluate. Flow motions in process equipment are very complex, and point conditions can be estimated sometimes only by visual means. And when it is not possible to write a point-to-point description of the flow pattern and forces involved, recourse is found in the principles of similitude that have been developed in the field of fluid mechanics. These principles provide a means whereby the parameters which affect fluid motion can be used to define motion in a macroscopic sense without the necessity of a detailed knowledge of point conditions of flow.

The basis of the principles of similitude of fluid motion lie in the assumption that when a force is applied to a fluid mass, the resulting acceleration assumes a direction dependent upon the boundaries of the system and the physical properties of the fluid. Boundaries take into account the shape, size, and location of all components of the system (*3*). Physical properties include the specific weight, density, viscosity, surface tension, compressibility. Thus, if two systems of different size have the same ratio of length for all corresponding boundaries and positions, the systems are said to be geometrically similar. Fluid motions are kinematically similar when the paths are geometrically similar and the ratio of velocities at corresponding points are equal to the ratio at other corresponding points. Finally, a condition of dynamic similarity will exist when geometric and kinematic similarity are present and when the ratio of masses and forces at corresponding points are equal to the ratios at other corresponding points. It follows that pressure intensities must also bear the same relation as forces.

A fluid motion may be described completely in terms of force, mass, length, and time, because all boundaries, velocities and fluid properties can be put in these dimensions (*3*). It is convenient to use the three units of force, length, and time (F-L-T) and to relate force and mass by Newton's second law, $F = Ma$. It is obvious that all linear boundaries of a system can be measured by the length dimension L. Velocities of motion may be designated by length and time, or by u which is equal to L/T. Direction of velocity can be given in linear coordinates. Forces may be represented by Ma or by pressure intensity p, where $p = F/L^2$. The physical properties of fluids can also be represented in force, length, and time. Specific weight γ is F/L^3, and thus gravity g is γ/ρ, or L/T^2. Density ρ (slugs per cubic foot) in force units is FT^2/L^4. Viscosity μ in force units is FT/L^2, and kinematic viscosity ν is μ/ρ, or L^2/T. Surface tension σ is F/L and kinematic interfacial tension ω is σ/ρ, or L^3/T^2. Elastic modulus e is F/L^2. All of the foregoing relations are listed for convenience in Table 1.

The kinematic notations are in terms of force per unit mass, and are therefore the ratio of the force property to the mass density.

The basic relations for similitude require equal ratios of dimensions, flows, and forces for corresponding points in two systems. Using subscripts 1 and 2 to denote two systems of different size, and subscript r for ratio, the following are the basic similitude equations:

Newton's second law:

$$F_r = M_r a_r \text{ and } F_r = \frac{\rho_r L_r^4}{T_r^2} \quad (1)$$

and

$$F_r = p_r u_r^2 L_r^2 \qquad (1a)$$

or, in terms of pressure intensity where $p = F/L^2$

$$p_r = \frac{\rho_r L_r^2}{T_r^2} \qquad (1b)$$

and

$$p_r = \rho_r u_r^2 \qquad (1c)$$

Also,

$$F_1 = F_r F_2 \qquad (2)$$

and

$$p_1 = p_r p_2 \qquad (2a)$$

and for dynamic similarity F_r or p_r must be constant.

For length, or coordinate position

$$L_1 = L_r L_2 \qquad (3)$$

L_r must be a constant for geometric similarity.

For time,

$$T_1 = T_r T_2 \qquad (4)$$

and T_r must be constant for kinematic similarity.

For the derived and physical properties:

for velocity, $u = L/T$:

$$u_1 = u_r u_2 \qquad (5)$$

and u_r must be a constant for kinematic similarity.

For density,

$$\rho_1 = \rho_r \rho_2 \qquad (6)$$

for viscosity,

$$\mu_1 = \mu_r \mu_2 \qquad (7)$$

or

$$\nu_1 = \nu_r \nu_2 \qquad (7a)$$

for specific weight

$$\gamma_1 = \gamma_r \gamma_2 \qquad (8)$$

or

$$g_1 = g_r g_2 \qquad (8a)$$

for interfacial tension

$$\sigma_1 = \sigma_r \sigma_2 \qquad (9)$$

or

$$\omega_1 = \omega_r \omega_2 \qquad (9a)$$

for elasticity

$$e_1 = e_r e_2 \qquad (10)$$

Force Ratios

The product of mass times acceleration is called an inertia force and is a resultant and equivalent to all forces acting on the mass. Hence, the inertia force can be equated to all forces entering into a fluid motion. It follows that the ratio of the inertia force to the other forces involved are dimensionless groups which can be used also to describe fluid motion. If such a ratio of inertia force to a fluid property force is constant for two sized geometrically similar systems wherein that property force is the only one operative then dynamic similarity obtains. This is equivalent to saying that F_r remains constant in Equation (2) when L_r is held constant in Equation (3).

It is possible to write by inspection the various ratios of the inertia force to other forces. Such ratios are known by name. For example, the ratio of inertia force to viscous force (*see* Table 1) is:

$$\left(\frac{\rho L^4}{T^2}\right) \div \left(\frac{\mu L^2}{T}\right) = \frac{L^2 \rho}{T \mu}$$

or

$$\frac{Lu\rho}{\mu} \text{ (Reynolds number)} \qquad (11)$$

Ratios for the other forces can be found in the same way and are listed in Table 1. They are:

Froude number $\frac{u^2}{Lg}$ (11a)

Weber number $\frac{u^2 L}{\omega}$ (11b)

Cauchy number $\frac{u}{e^{1/2}}$ (11c)

If it can be experimentally determined that a fluid motion is dependent upon viscosity, then the value of the Reynolds number must be constant for any values of size L if the force ratio at these sizes is to be constant. Conversely, if it can be shown that the Reynolds number is constant at various sizes, then dynamic similarity will have been achieved if viscosity is the only active fluid property force.

Velocity Ratio in Scale-up

It is also evident that the inertia force can be equated to any one of the fluid property forces. This will result in a relation useful for scale-up to dynamically similar conditions. For example, considering again the case of the viscous force; if it is the only fluid property force effective, then

$$\frac{\rho L^4}{T^2} = \frac{\mu L^2}{T}$$

and by rearranging for velocity

$$\frac{L}{T} = \frac{\mu L^2 T}{\rho L^3 T} \quad \text{or} \quad u = \frac{\mu}{\rho L}$$

and for similarity, applying Equations (3), (5), (6) and (7)

$$u_r = \frac{\nu_r}{L_r} \qquad (12)$$

This states that the velocity ratio at corresponding points in two systems is directly proportional to the kinematic viscosity and inversely proportional to the length ratio, or scale, of the two systems. Therefore, under these force conditions, velocity occurrences at cor-

TABLE 2. REQUIREMENTS FOR SIMILITUDE.

	RATIOS WHICH MUST REMAIN CONSTANT	DIMENSIONLESS GROUP	FOR SCALE-UP				EXAMPLE OF VELOCITY RATIO FOR SCALE-UP OF 2
			VELOCITY RATIO REQUIRED	WHEN WEIGHT AND VISCOSITY BOTH ACT	WHEN WEIGHT AND TENSION BOTH ACT	WHEN VISCOSITY AND TENSION BOTH ACT	SINGLE FORCE CONTROLLING
FORCE (Inertia)	$\frac{\rho_r L_r^4}{T_r^2} = F_r$	$N_E = \frac{p}{\rho u^2 L^2}$	$u_r = \sqrt{\frac{F_r}{\rho_r L_r^2}}$				$u_r = 0.5$
LENGTH	$\frac{L_1}{L_2} = L_r$	L_r	$L_r = C$	$L_r = \nu_r^{2/3}$	$L_r = \sqrt{\omega_r}$	$L_r = \frac{\nu_r^2}{\omega_r}$	
TIME	$\frac{T_1}{T_2} = T_r$	T_r	$T_r = C$				
VELOCITY	$\frac{u_1}{u_2} = u_r$	u_r					
DENSITY	$\frac{\rho_1}{\rho_2} = \rho_r$	ρ_r					
PRESSURE	$\frac{p_1}{p_2} = p_r$	$N_p = \frac{p}{\rho u^2}$	$u_r = \sqrt{\frac{p_r}{\rho_r}}$				
WEIGHT	$\frac{\gamma_1}{\gamma_2} = \gamma_2$	$N_{Fr} = \frac{u^2}{Lg}$	$u_r = \sqrt{L_r}$	$u_r = \sqrt{L_r}$	$u_r = \sqrt{L_r}$		$u_r = 1.41$
VISCOSITY	$\frac{\nu_1}{\nu_2} = \nu_r$	$N_{Re} = \frac{Lu}{\nu}$	$u_r = \frac{\nu_r}{L_r}$	$u_r = \frac{\nu_r}{L_r}$		$u_r = \frac{\nu_r}{L_r}$	$u_r = 0.5$
INTERFACIAL TENSION	$\frac{\omega_1}{\omega_2} = \omega_r$	$N_{We} = \frac{Lu^2}{\omega}$	$u_r = \sqrt{\frac{\omega_r}{L_r}}$		$u_r = \sqrt{\frac{\omega_r}{L_r}}$	$u_r = \sqrt{\frac{\omega_r}{L_r}}$	$u_r = 0.71$
ELASTICITY	$\frac{e_1}{e_2} = e_r$	$N_E = \frac{u^2}{e}$	$u_r = \sqrt{e}$				
TO DETERMINE		RATIO OF INERTIA TO OTHER PROPERTY FORCE	EQUATE INERTIA TO OTHER PROPERTY FORCE	EQUATE VELOCITY RATIOS	EQUATE VELOCITY RATIOS	EQUATE VELOCITY RATIOS	SUBSTITUTE IN VELOCITY EQUATION

responding points in a system twice the size which contained the same fluid at the same temperature and pressure, would be one half of the velocities in the smaller system.

Equations like (12) for other properties are determined in the same way, they are:

When weight (or gravity) controls $u_r = (L_r/g_r)^{1/2}$, the force of gravity is approximately constant all over the surface of the earth and the ratio $g_r = 1$, so the relation is usually written as

$$u_r = \sqrt{L_r} \qquad (12a)$$

When interfacial tension controls

$$u_r = \sqrt{\frac{\omega_r}{L_r}} \qquad (12b)$$

When elasticity (or compressibility) controls

$$u_r = \sqrt{e_r} \qquad (12c)$$

These are listed in Table 2. They are referred to as velocity ratio in scale-up, or as "model laws."

By means of these relations it is possible to account for fluid motion differences or similarities in equipment of different size. It is also possible to compute equipment size necessary for desired fluid velocities.

Two Property Forces

When two fluid properties influence fluid motion a summation of the individual effect of each can be made, but without experimental data it is not possible to predict the relative effect of each. However, when two property forces are known to apply, each ratio of inertia force to property force must be constant for any change in the force, length, time scales. For example, assuming a fluid motion where both viscosity and specific weight are effective, the force ratios which can be used as parameters (Table 1) are the Reynolds number and the Froude number. From the previous discussion it is evident that for a different size system, geometrically similar, the Reynolds number must be constant to achieve dynamic similarity. Likewise, the Froude number gives the value of the ratio of inertia forces to weight forces (since $\gamma = \rho g$, the Froude number is often referred to as the ratio of inertia to gravity forces) and if F_r (weight) of Equation (2) is to be constant while L_r of Equation (3) is constant as required for similitude, then the Froude number also must be constant as size is changed.

These requirements for similitude impose restrictions on the scale-up possibilities. From Table 2 and Equation (12) the velocity ratio due to viscous forces in size change, or scale-up, is inversely proportional to size. So, using the same kinematic viscosity, if the L_r were 2, then the velocities in the larger system would be one-half those in the smaller. The velocity ratio in scale-up due to weight (or gravity) is given in Equation (12*a*) and in Table 2. Accordingly, for L_r of 2, the velocities in the larger system would be $\sqrt{2}$, or 1.41 times those in the smaller. The viscous forces thus tend to reduce velocity as size increases, whereas the weight forces increase velocities. For dynamic similarity to exist u_r must be constant for any size system regardless of what forces are operative. Therefore, u_r (viscosity) must equal u_r (weight). By equating the velocity scale ratios (Equations (12) and (12*a*))

$$\frac{v_r}{L_r} = \sqrt{L_r}$$

$$v_r = L_r^{3/2} \qquad (13)$$

This shows that dynamic similarity under these conditions cannot exist for the same fluid at the same temperature and pressure. If L_r is 2, then the kinematic viscosity of fluid in the large system must be $2^{3/2}$, or 3.83, times that in the small one.

Equation (13) states the relation between viscosity and scale for dynamic similarity of flow. To determine the velocities of flow at various scales, either of the two velocity ratio equations for scale-up will yield the same result, because the value of ν in Equation (12) is fixed by Equation (13) so that u_r (viscosity) will be equal to u_r (weight).

Other pairs of force properties can be handled in the same way. Several possible combinations are listed in Table 2. They are:

For the case when specific weight and interfacial tension play the significant roles, the velocity ratios for each are equated, resulting in

$$L_r = \sqrt{\omega_r} \qquad (13a)$$

When viscosity and interfacial tension are both effective,

$$L_r = \frac{v_r^2}{\omega_r} \qquad (13b)$$

The relations which have been developed in the foregoing discussion are summarized in Tables 1 and 2. The various force dimensions, notations and dimensionless groups are given in Table 1. Table 2 shows the equations required for similitude for various fluid property forces, normally affecting fluid motion.

Distorted Models

It may not be convenient or possible to change such properties as interfacial tension and viscosity or other properties as required by the relations of Table 2 to achieve similarity. In such cases the effect of one or more property may be minimized by distorting the model. For example, interfacial tension is minimized by avoiding sharp fluid surface curvature.

If viscosity is one of two effective forces it is possible to minimize its effect, or even to render it negligible by operating at high velocities to achieve high Reynolds numbers. If at the same time it is possible to evaluate the other force parameter, it may then be possible to approximate a combined effect. In the event that individual parameter effects can be evaluated by such means it can be assumed for practical purposes that the individual forces dependent upon each parameter can be added together. Such is the technique as developed by Froude for the case of viscous and gravity forces operating on the hull of a ship, and the use of models for experimental work to determine the power necessary to drive ships of various designs is based on the principle that the force functions are additive. This is analogous to the well-known experimental technique of holding all variables constant except one, so that each variable may in turn be evaluated.

More than Two Property Forces

When three force properties play a part in fluid motion it is rarely possible to reproduce dynamic similarity on any other size equipment. It is clear from inspection of the velocity ratios for scale-up that if more than two of them are equated at a time, it restricts the physical properties of the fluids so that there is little possibility of choosing actual liquids that will meet the requirements. It is sometimes possible to distrot models (*5*) and to evaluate the effect of individual forces independently: this was discussed in the preceding paragraph.

Determination of Applicable Parameters

Equations (1)-(10) can be used to describe all flow motions, in which they represent all the variables and boundaries. However, the interrelation between them must be known and related to Newton's second law as shown in Equations (10)-(13) and as tabulated in Table 2. The interplay of forces due to fluid properties, boundary conditions, and any imposed work force results in a definite flow regime. Such an interplay of forces may result in various combinations of the similitude equations. If an equation can be written to describe a fluid motion completely, then a grouping of properties, boundaries, and forces can be found which can be used as a parameter for conditions of dynamic

similarity. Unfortunately such a technique is often difficult and, therefore, cut-and-trial means for determining parameters are frequently used. The relations just reviewed cannot be used to predict which forces will take part or to what degree they might interact, except in a qualitative way.

Inertia forces predominate whenever the flow pattern is constant over a relatively wide range of velocities. Inertia forces are, of course, always present in any flow motion, as postulated by Newton. Since the property force parameters are all ratios of inertia to the property force, it follows that for high values of the Reynolds, Froude, and Weber numbers, the inertia forces predominate, and viscous, weight, and interfacial tension forces play a minor role. Conversely, low values of these parameters indicate that the corresponding fluid properties may play an effective role.

Weight (or gravity) forces are effective wherever waves or vortexes are present in a fluid interface, and when the Froude number is relatively small.

Viscous forces are effective when the viscosity is high, or when there is not much turbulence, or when the Reynolds number is low.

Interfacial tension forces may be important when there is sharp surface or interface curvature or where interfacial tensions are large, or where the Weber number is relatively low.

Elastic forces may be of importance when the modulus of elasticity or compressibility is small, or where pulsations are frequent, or when the Cauchy number is high.

One technique often used to determine which parameters may be useful in correlating or characterizing flow motion is that of Dimensional Analysis. The Pi theorem of Buckingham (*3*), and the method of Rayleigh (*12*) are based on the premise that a general function of all variables which contribute to a flow motion can be stated, and that these variables can be arranged in a variety of dimensionless groups depending on the arbitrary choice of four variables. Either of these two methods can be used and will give identical results. The Froude, Reynolds, Weber, and Cauchy numbers can all be derived in identical form to those just shown and in Table 2. In addition, all the length ratios which are inherent in the boundary dimensions of the system can be derived.

To illustrate the use of these techniques, assume that all factors influencing a flow motion are: (1) A series of linear (L) boundary dimensions a, b, and c. (2). A mean velocity u in the direction of a pressure intensity p. (3). Specific weight γ, density ρ, and viscosity μ of the fluid.

Then

$$f(a,b,c,u,p,\gamma,\rho,\mu) = 0 \qquad (14)$$

If this is operated on by either the Buckingham or Rayleigh technique (*18*), the result is:

$$\frac{p}{\rho u^2} = f\left(\frac{a}{b}, \frac{a}{c}, \frac{u^2}{ag}, \frac{au}{\nu}\right) \qquad (15)$$

The left-hand term will be recognized as the Newton inertia force group in pressure units (Eq. 1c). The first and second terms on the right are both linear ratios, and the third and fourth terms are the Froude and Reynolds numbers respectively. The a dimension was chosen as the reference length. Note that the dimensionless ratios of inertia force to property force as derived earlier from Equation (1) could have been written directly in the form of Equation (15), and the boundary dimension ratios are a requirement of geometric similarity since all dimension ratios must stay constant for geometric similarity (Eq. (3)) if any one dimension is changed. So, if Equation (14) can be deduced, Equation (15) may be written by inspection based on the similarity requirements of Equations (1)-(10).

Regardless of the technique used to determine an equation like (15), such an equation does not of itself show the interrelation between the various factors involved. Furthermore, its validity is dependent upon that of Equation (14). Hence, the importance and interrelation of the groups in an equation like (15) are not known until they are evaluated by experiment. If experimental data are available then each dimensionless ratio of an equation like (15) can be used in turn as a parameter and evaluated. Graphical means are often employed for such evaluations. Figure 1 is one example showing how the inertia forces are evaluated in terms of the Reynolds and Froude numbers for fluid motion in a mixing tank (*18*). At best, however, these methods simply show the effect of various properties and geometry by the indirect method of assuming an influence and then substantiating it if possible by experiment: a type of cut-and-trial technique to obtain parameters for correlation of data.

There is a direct method by which Equations (1)-(10) can be used to give the significant parameters for flow motion directly. It is dependent upon ability to write a differential equation to express a particular flow motion. The technique can best be illustrated by the general equations of Navier-Stokes for the case of noncompressible viscous flow (*21*). The first of the Navier-Stokes equations for flow, omitting the divergence term, is for system 1.

$$-\frac{1}{\rho_1}\frac{\partial p_1}{\partial x_1} + \frac{\mu_1}{\rho_1}\left(\frac{\partial^2 u_1}{\partial x_1^2} + \frac{\partial^2 u_1}{\partial y_1^2} + \frac{\partial^2 u_1}{\partial z_1^2}\right) = \frac{u_1\partial u_1}{\partial x_1} + \frac{v_1\partial u_1}{\partial y_1} + \frac{w_1\partial u_1}{\partial z_1} + \frac{\partial u_1}{\partial T_1} \qquad (16)$$

If this equation is written for another system 2, with the proper alteration of length, time, and force (or pressure in this case) scales, the result will be an equation for a completely similar flow. The proper scales for similarity will be those of Equations (1)-(10) which may apply. Thus if Equation (3) in terms of x is written as $x_1 = L_r x_2$, and similarly for y and z, and also Equations 2a,

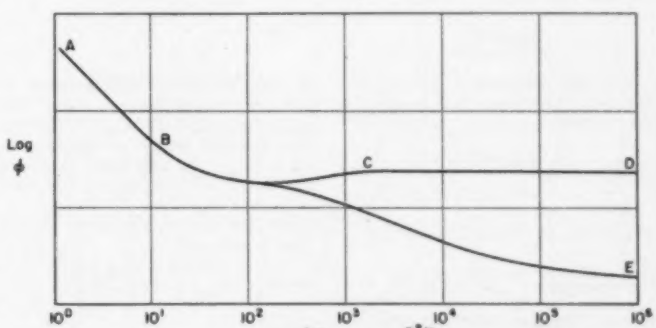

Fig. 1. Power characteristics of a mixing impeller.

4, 5, 6, and 7 are substituted in Equation (16) the result is

$$-\frac{p_r}{\rho_r L_r}\left(\frac{1}{\rho_2}\right)\left(\frac{\partial p_2}{\partial x_2}\right) + \frac{\mu_r u_r}{\rho_r L_r^2}\left(\frac{\mu_2}{\rho_2}\right)\left(\frac{\partial^2 u_2}{\partial x_2^2}+\frac{\partial^2 u_2}{\partial y_2^2}+\frac{\partial^2 u_2}{\partial z_2^2}\right) = \left(\frac{u_r^2}{L_r}\right)\left(\frac{u_2\partial u_2}{\partial x_2}+\frac{v_2\partial u_2}{\partial y_2}+\frac{w_2\partial u_2}{\partial z_2}\right) + \frac{u_r}{T_r}\left(\frac{\partial u_2}{\partial T_2}\right) \quad (17)$$

For dynamic similarity Equation (17) must equal Equation (16). This is true when the coefficients of Equation (17) are equal, or

$$\frac{p_r}{\rho_r L_r} = \frac{\mu_r u_r}{\rho_r L_r^2} = \frac{u_r^2}{L_r} = \frac{u_r}{T_r} \quad (18)$$

These groups each must be satisfied for dynamic similarity for viscous flow.

Inspection of the third and fourth terms show that they are obviously equal.

The second and third terms,

$$\frac{\mu_r u_r}{\rho_r L_r^2} = \frac{u_r^2}{L_r}$$

$$\frac{L_r u_r \mu_r}{L_r^2 u_r^2 \rho_r} = 1 \quad \text{or} \quad \frac{\mu_r}{L_r u_r \rho_r} = 1$$

and is dimensionless, and by substituting according to Equations (3), (5)-(7) there results

$$\frac{L_1 u_1 \rho_1}{\mu_1} = \frac{L_2 u_2 \rho_2}{\mu_2} = N_{Re} \quad (19)$$

The Reynolds number so derived shows that this form is necessary for dynamic similarity.

Equating the first and third terms of Equation (18) gives

$$\frac{p_r}{\rho_r L_r} = \frac{u_r^2}{L_r}$$

or $p_r = \rho_r u_r^2$ which is Equation (1c). Equation (1c) is equal to Equation (1), and it may be written as

$$\frac{F_r}{\rho_r u_r^2 L_r^2} = 1 \text{ the Newton inertia group} \quad (20)$$

substituting, and letting L^2 = area A

$$\frac{F_1}{\rho_1 u_1^2 A_1} = \frac{F_2}{\rho_2 u_2^2 A_2} = N_I$$

This is sometimes called the drag coefficient, and is the other dimensionless parameter which must be constant in dynamically similar viscous flow.

Equating the first and second terms of Equation (18)

$$\frac{p_r}{\rho_r L_r} = \frac{\mu_r u_r}{\rho_r L_r^2} \text{ and let } p = F/L^2$$

then

$$\frac{F_r \rho_r L_r^2}{L_r^2 \rho_r L_r \mu_r u_r} = \frac{F_r}{L_r \mu_r u_r} = 1 \quad (21)$$

and this is another dimensionless form of the Newton inertia group. Either Equation (20) or (21) can therefore be used to characterize the inertia forces.

Thus, from the differential equation it is shown that the Reynolds and inertia groups are sufficient to satisfy dynamic similarity for viscous flow. If, therefore, a differential equation can be written to describe any complex flow motion, the dimensionless parameters necessary for similarity can be obtained directly, and those obtained in this way should be complete and sufficient for the purpose. If the differential equation can be solved, the interrelation between the parameters can be obtained. Otherwise the interrelations must be obtained through experimental data.

Experimental Data

Experimental data involving force and various values of length and time can be used as shown in Figure 1 to relate the various fluid motion parameters (*18*). Figure 1 is a curve relating the inertia force to the Reynolds and Froude numbers for a mixing impeller, but the curve *ABCD* is also typical of the general relation for fluid drag in a pipe or across any solid surface. A brief review of the significance of this logarithmic plot is pertinent.

At low Reynolds numbers the part of the curve *AB* has a slope of −1 and can be represented (from Equation (15)) by

$$\frac{F}{\rho u^2 L^2} = K'\left(\frac{Lu\rho}{\mu}\right)^{-1}$$

giving

$$F = K' L u \mu \quad (22)$$

showing that force is proportional to size, velocity and viscosity under these conditions, called viscous flow, and that these relations hold in similitude. The value of K' is determined from the position of the curve, and is thus fixed by experimental data.

For that part of the curve *CD*, the slope is zero and

$$\frac{F}{\rho u^2 L^2} = K''\left(\frac{Lu\rho}{\mu}\right)^{0}$$

giving

$$F = K'' \rho u^2 L^2 \quad (23)$$

This shows that viscous forces are not controlling under these conditions. The flow is one of fully developed turbulence. The value of K'' can be determined from the curve and is fixed by experimental data.

For curves such as *BE*, similar equations can be developed depending on the slope, but in these cases it is evident that viscous forces are effective over the entire curve *ABE*.

Correlation of experimental data in this way allows evaluation of the importance of the force parameters. It is evident that the slope of the line in such a plot as in Figure 1 gives the relative effect of the inertia group and the Reynolds group, and thus the interaction of properties in geometrically similar systems. When the slope of the line *AB* is −1 it shows that the inertia force is directly proportional to the viscous force: hence, viscous forces alone are dominant in defining the flow motion. When the slope of the curve is zero then the inertia force is independent of viscous forces. Furthermore, since similitude is based on Newton's law, the flow pattern is defined by the inertia group. Hence, a flow pattern or motion pattern will be the same in two different sized systems only when the inertia group is the same. If viscous forces control, as for *AB*, then they affect the flow pattern: a change of Reynolds number will change the flow pattern. Therefore, while it is possible to reproduce the same flow pattern in two different sized systems it is not possible to reproduce the same velocities in the two systems with the same viscosity liquid. This is a corollary of Equation (12).

When viscous forces do not control line *CD*, then the Reynolds number has no effect on the flow pattern, and the flow pattern is constant over the entire range of fluid velocities represented by all the Reynolds numbers from *C* to *D*. A velocity at one point in a system will bear a definite relation to all other velocities in the same system, and in a kinematically similar system, the velocity distribution will have the same relations at corresponding points. Therefore, if the inertia group is constant, the velocity at one point (or average) can be varied and the same flow motion pattern will result. It is possible, then, to reproduce a flow motion pattern and the same velocities of flow at corresponding points in systems of two different sizes when there is fully developed turbulence. Fully developed turbulence may be defined by a slope of zero for the line *CD*.

The importance and interaction of other property forces can be analyzed in the same way provided that the data are available and sufficient to determine the effect of one force parameter independent of the others.

(Part II of this paper will contain Figures 2, 3, and 4, and Notation, Literature Cited, and Discussion.)

THE EFFECT OF PULSATIONS ON HEAT TRANSFER

Turbulent Flow of Water Inside Tubes

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Water film coefficients of heat transfer inside tubes for heating and cooling at Reynolds numbers of 30,000 to 85,000 have been increased as much as 60 to 70% by the use of partially dampened pulsating flow from a reciprocating pump. There appears to be an optimum degree of dampening since severe pulsations were not as efficient and resulted in more vibration than moderate pulsations.

Crude power consumption measurements have been interpreted to indicate an increase of no more than 30% in the net power consumption after subtraction of no-load losses of the pump and motor for the region of the optimum pulsations. It appears that the method should have applications both to new design and also to increasing the capacity of existing heat exchangers.

A NUMBER of methods have been used for reducing the thickness of the laminar film and transition layer which separate a heat-exchanger tube from a turbulent core of fluid flowing within the tube. Various types of turbulence promoters such as coiled wires, spirals of various pitches, and propeller-shaped baffles have been reported by Royds (*11*), Colburn (*3*), Nagaoka and Watanabe (*9*), and Siegal (*12*). The fins sometimes used to extend heat-exchanger-tube surfaces also serve a similar purpose (*5*). The applicability of such devices depends on a three-way balance between reduction in investment in heat-transfer area, increase in investment and maintenance due to the turbulence promoters themselves, and the net change in power consumption for the same heat-transfer performance. A somewhat different approach has been advanced by Andreas (*1*) who considered the mechanical vibration of an entire heat exchanger. Andreas recommended vibration with an amplitude of 1 to 5 mm. in the direction of the tube with a minimum frequency of 1500 vibrations/min. Martinelli and Boelter (*6*) also have studied the effect of vibration on heat transfer from a cylinder.

The present investigation concerns the effect of pulsations in the flow rate on the rate of heat transfer in heat-exchanger tubes. Such pulsations can be produced readily by reciprocating pumps. In many heat exchangers pulsating flow already exists or could easily be produced by altering the air chambers commonly used to dampen the pulsations from reciprocating pumps. It was expected that pulsations would improve heat transfer in two ways: (1) the peak longitudinal flow would be increased which should decrease the film thickness, and (2) the subsequent minimum longitudinal flow should result in radial diversion of much of the excess longitudinal kinetic energy. The magnitude of the improvement compared with the increased power consumption could only be found by experiment.

The present article is limited to the effect of pulsating flow on water heat-

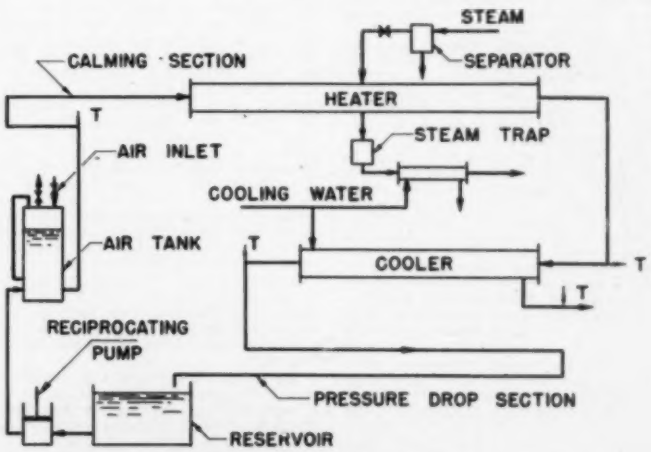

Fig. 1. Flow sheet of apparatus.

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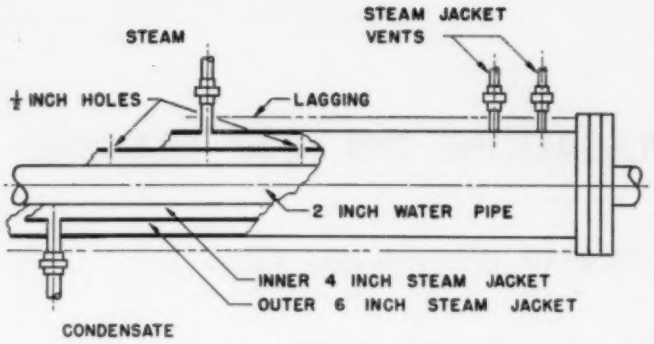

Fig. 2. Details of steam-water heat exchanger.

transfer coefficients at what would have been Reynolds numbers of 30,000 to 85,000 for steady flow. Parallel investigations (*8, 13*) at Reynolds numbers of 26 to 1375 showed no improvement.

Heat-Transfer Apparatus

The principal equipment consisted of a reciprocating pump, a variable air chamber, a steam water heater, a water-cooler, and a pressure-drop section. The flow sheet appears in Figure 1.

Water from a large reservoir was circulated through the system by means of a Worthington Triplex pump. The pump had been modified by removing its air chamber and two of its three pistons. The remaining piston had a 3.5-in. diam. and a 4-in. stroke. It was driven at approximately 100 rev./min. by a 15 hp., three-phase motor. The input power was measured at the switch box by the two-wattmeter system.

The water pulses from the pump passed through a vertical cylindrical tank containing an amount of air which could be adjusted to give any desired degree of pulsation in the stream leaving the tank. The steel tank was 9 in. in diam. and 30 in. tall. It was provided with compressed air-inlet and air-outlet connections for adjusting the air volume during operation. The water level was read by means of a gauge glass. At first the water level in the gauge glass oscillated much more than corresponded to the volume of each pulse. This was attributed to momentum effects and was offset by throttling the water inlet to the gauge glass until the fluctuations in level were reduced to one-fourth to one-half inch, of the same order as the theoretical fluctuation.

The pulsating stream of water from the air chamber entered the steam-water heat exchanger through a 9-ft. calming section of well-lagged 2-in. pipe. The heater consisted of a horizontal 20-ft. length of 2-in., schedule 40, galvanized iron pipe which was steam-jacketed for 18.17 ft. A double jacket was used to eliminate heat loss from all but the ends of the inner steam jacket. It consisted of concentric 4-in. and 6-in. iron pipes arranged with steam inlets, vents, and separate condensate drains as shown in Figure 2. Wet steam at 125 lb./sq.in. gauge was dried by passage through a steam separator and then was throttled by a reducing valve to approximately 10 lb./sq.in. gauge as measured by a calibrated Bourdon gauge. It entered the top of the lagged outer jacket through four ¼-in. inlets spaced 4 ft. apart, and from there entered the top of the inner jacket through 18 0.5-in. holes spaced 1 ft. apart. Inerts were purged with excess steam through vents from both jackets located at both ends of the exchanger. Condensate dripped from the inner water pipe and ran along the bottom of the inner jacket in contact with steam to one of six 0.5-in. drains. The drains discharged through a common header to a single bucket-type steam trap. Condensate leaving this trap was cooled to prevent flashing prior to weighing on scales which were accurate to within 0.5% for the weights of condensate collected. Condensate from the outer jacket was removed through a separate steam trap and was not collected. Temperatures of the inlet and outlet circulating water were obtained by 0.2° C., thermometers in a thermowell ahead of the calming section and in another 2 ft. beyond a cross used as an elbow in the outlet line.

The water from the heater was cooled by means of a horizontal cold water-jacketed section of 2-in., schedule 40, galvanized-iron pipe. The jacket consisted of a section of 3-in., schedule 40, galvanized-iron pipe connected through reducers to a packing gland near either end of the inner pipe. The cooling water connections were located approximately 4 in. from the packing glands, so an arbitrary allowance has been made for a 2-in. stagnant pocket at both ends of the jacket. This reduced the total jacketed length from 99.5 to 95.5 in. No insulation was used. The inner pipe protruded from the jacket far enough to give an over-all calming section of 8 in. including the assumed stagnant pocket. The hot water entered this short calming section through a pipe tee used as an elbow and bearing a thermowell for measuring the outlet water temperature from the heater which was also the inlet water temperature to the cooler. The outlet water temperature from the cooler was measured at a thermowell in a pipe cross used as an elbow 8 in. beyond the jacket. The outlet cooling water temperature was obtained by a similar thermowell, while the inlet cooling water temperature was obtained elsewhere in the laboratory.

In order to raise the power consumption of the pump to a level which could be measured by the wattmeters with any accuracy, the cooled water was forced through a 24-ft. section of ¾-in., schedule 40, black-iron pipe.

The cooled water finally was discharged back to the reservoir, to the sewer, or to a large tank for checking the flow rate. The tank was set on a platform scale which was found to be accurate within 0.5%. The tank leaked slightly, but the leakage rate was measured and corrected for.

Operating Procedure

Two series of runs were made, one with the water being recirculated through the system to give an inlet temperature of approximately 75° C., and the other with fresh tap water at approximately 15° C. Data were taken over the heater in both series and over the cooler in the second series. The primary variable in each series was the water level in the air tank which determined the degree of pulsation.

The procedure in the first series was as follows:

Water was pumped through the system and back to the reservoir. Steam was admitted to the heater and adjusted to 10 lb./sq.in. gauge, the condensate discharging to the drain. When the inlet circulating water had reached 75° C., the cooling water was turned on and the air volume in the air chamber was adjusted. The system was allowed to run until steady-state conditions were attained which required approximately 30 min. Condensate from the inner steam jacket was then collected for a 15-min. period and weighed. The level in the air tank was checked and adjusted if necessary every five minutes during this period. Temperatures, steam pressure, and power input to the pump's motor were recorded at five-minute intervals. The circulating water rate was measured at the end of the run by collecting it for a period of one to three minutes and weighing. In most cases a duplicate run was then made repeating all measurements except for the total water flow. Run 23 was made with so small an air volume that the entire apparatus vibrated badly, and the data were taken as rapidly as possible without waiting long enough to insure steady-state conditions.

The procedure in the second series of runs was essentially the same except that none of the water was recirculated and temperature measurements were also made over the cooler. Steady-state conditions were attained rapidly with the constant inlet-water temperature. The colder water increased the rate of condensation so greatly that the condensation collection period was shortened to ten minutes and readings were taken at three-minute intervals. The total water flow was measured at the end of the first run for each new air volume, the water being collected for three minutes. Duplicate runs were made at each air volume.

Pulsation Ratio. A "pulsation ratio" has been defined to characterize the pulsations resulting from various water levels in the air chamber. This is the ratio of the maximum air volume to the minimum air volume in the air chamber over the cycle of one pulsation. This also would be the ratio of the maximum to the minimum absolute pressures in the chamber if the air temperatures were the same. Hence low pulsation ratios correspond to slight pulsations and high ratios to large pulsations.

Since it was impossible to measure the maximum and minimum air levels with precision in the present investigation, the minimum level was measured as accurately as possible, and the difference between the minimum and maximum volumes was calculated. The minimum air volume was found from the minimum air height in the 9-in. diam. tank as recorded in Table 1. It was necessary to add 25 cu.in. to this volume to allow for the air in the external air inlet and outlet lines. At low pulsation ratios where the water outflow rate from the tank is nearly constant, it is possible to calculate the crankshaft angles for which the inflow rate should equal the constant outflow rate. For the 9-in. connecting rod used here these angles were

TABLE 1.—TABULATION OF DATA AND RESULTS FOR THE HEATER

Run No.	Air Tank Min. Air Height Inches	Pulsation Ratio	Water Rate lb/min.	Circulating Water Temp. t_{in} °C	Circulating Water Temp. t_{out} °C	Steam Press. lb/ (sq.in.) gauge	Condensate Rate lb/hr.	Heat Transferred Btu/hr.	Heat Balance % Error	Heat Transfer Coefficients Btu/(hr)(sq.ft)(deg F) U	h_j	h_w	h_w^*	h_w^*/h_w	Gross Power Consumed Watts
1	15.2	1.02	135	74.52	89.98	9.65	234	214,500	- 3.0	385	2255	552	536	0.972	2370
2	15.2	1.02	141.6	74.32	89.08	10.0	246.5	225,400	- 4.3	385	2225	573	536	0.936	2456
3	15.2	1.02	141.6	75.16	89.87	10.4	245	224,700	- 3.9	389	2230	575	545	0.948	2331
4	15.2	1.02	145.8	75.58	90.49	11.4	252.5	232,900	- 3.6	395	2220	591	557	0.942	2426
5	15.2	1.02	142.5	75.58	90.11	10.5	233	224,400	- 3.5	388	2267	591	543	0.918	2343
6	7.6	1.04	132.5	74.65	89.55	9.4	234.5	215,000	- 4.8	382	2250	545	532	0.976	2325
8	3.8	1.08	143.0	75.72	90.86	10.4	247	233,800	0.5	414	2220	578	595	1.030	2386
10	2.3	1.12	140.4	75.34	89.80	9.4	242	219,200	- 5.2	389	2230	571	544	0.952	2259
11	2.3	1.12	140.4	75.42	89.91	9.8	242.7	219,600	- 5.3	390	2235	571	547	0.958	2241
12	1.5	1.16	142.3	74.30	92.20	10.2	291	271,300	- 2.1	456	2100	579	629	1.207	2640
13	1.5	1.16	142.3	74.95	92.06	10.6	286	263,200	- 3.4	455	2124	576	715	1.237	2437
14	1.1	1.22	142.3	74.00	92.59	10.4	289	266,000	3.8	511	2115	576	832	1.447	2406
15	1.1	1.22	142.3	75.00	92.70	9.9	279.5	272,000	2.1	505	2140	575	815	1.417	2460
16	0.6	1.28	141.2	75.14	91.36	10.6	269	247,300	- 3.5	429	2170	576	630	1.094	2480
17	0.6	1.28	130.5	75.58	93.30	10.3	281	256,000	- 4.7	474	2135	540	737	1.365	2460
18	0.6	1.28	130.5	75.75	93.54	10.0	273	250,500	- 3.8	478	2140	540	745	1.381	2451
19	0.4	1.42	130.5	75.40	93.66	9.4	281	260,000	- 3.1	510	2130	536	830	1.548	2407
20	0.4	1.42	130.5	75.25	93.98	10.0	286.5	264,000	- 4.0	501	2105	539	806	1.496	2407
21	0.2	1.56	141.2	75.16	91.69	10.4	282.5	252,200	- 6.7	451	2115	575	684	1.189	2110
22	0.2	1.56	141.2	75.48	91.62	10.1	275.5	246,100	- 6.5	446	2145	575	671	1.167	2803
23	0.0	1.64	143.0	75.90	92.98	11.6	284.5	263,700	- 2.4	463	2140	581	710	1.222	2157
24	15.2	1.02	140.5	14.55	46.97	10.7	500	491,000	3.2	328	1570	449	456	1.021	1900
25	15.2	1.02	140.5	14.56	47.08	10.8	501.5	489,400	2.5	326	1571	449	455	1.014	1956
26	7.6	1.04	140.0	14.62	46.56	10.0	495	483,000	2.4	324	1570	448	451	1.010	1923
27	7.6	1.04	140.0	14.64	46.53	10.0	495.5	481,500	1.9	323	1570	448	448	1.004	1862
28	3.8	1.08	138.7	14.70	46.59	9.8	491	477,000	1.9	324	1575	441	450	1.020	1825
29	3.8	1.08	138.7	14.70	46.99	10.6	497.5	482,500	1.9	325	1573	443	451	1.020	1845
30	2.3	1.12	147.5	14.55	46.60	10.5	563.5	545,000	1.6	370	1610	461	549	1.189	2057
31	2.3	1.12	147.5	14.66	46.78	11.0	556	543,000	2.3	364	1617	463	537	1.160	2042
32	1.5	1.16	147.0	14.70	47.06	10.7	551	506,000	0.6	336	1636	464	476	1.026	1917
33	1.5	1.16	147.0	14.70	46.95	10.7	530	506,000	0.4	340	1636	463	483	1.043	1925
34	1.1	1.22	146.6	14.60	46.76	11.2	529.5	508,000	1.0	338	1640	461	480	1.040	1977
35	1.1	1.22	146.6	14.60	46.89	11.3	528	511,000	1.5	340	1644	462	484	1.045	1955
36	0.8	1.28	137.7	14.6	56.44	9.8	633	616,000	2.5	450	1547	436	760	1.747	2075
37	0.6	1.28	137.7	14.64	55.80	10.2	639	608,000	- 0.1	437	1544	436	725	1.666	2130
38	0.4	1.42	139.2	15.05	56.46	10.1	644.5	621,000	1.4	452	1542	436	766	1.756	2186
39	0.4	1.42	139.2	15.10	56.19	10.2	632.2	616,000	2.5	446	1550	436	749	1.715	2077
40	0.2	1.56	139.2	14.99	54.51	10.3	614.2	594,000	2.5	421	1560	436	678	1.549	2087
41	0.2	1.56	139.2	14.92	54.59	9.7	608.2	596,500	2.8	429	1561	436	698	1.593	2123

TABLE 2.—TABULATION OF DATA AND RESULTS FOR THE COOLER.**

Run No.	Pulsation Ratio	Cooling Water tin °C	Cooling Water tout °C	Circulating Water Temp. tout °C	U	Heat Transfer Coefficients Btu/(hr.)(sq. ft.)(deg F) h_j	h_w	h_w*	h_w*/h_w
24	1.02	14.55	16.23	42.9	272.0	880	354	426	1.204
25	1.02	14.78	16.40	42.9	275.6	816	356	451	1.270
26	1.04	14.67	16.38	42.5	271.0	837	352	433	1.230
27	1.04	14.64	16.35	42.5	263.5	841	350	414	1.181
28	1.08	14.70	16.38	42.8	259.4	809	350	410	1.172
29	1.08	14.70	16.39	43.0	258.4	836	349	402	1.152
30	1.12	14.55	16.71	44.5	284.0	751	376	495	1.317
31	1.12	14.66	16.90	44.4	289.3	749	376	511	1.360
32	1.18	14.70	16.60	43.0	283.0	801	370	475	1.284
33	1.18	14.70	16.65	43.0	276.4	758	370	470	1.270
34	1.22	14.60	16.40	42.9	272.2	763	368	456	1.242
35	1.22	14.60	16.54	43.0	272.2	762	368	458	1.242
36	1.28	14.80	17.90	49.8	343.6	773	380	693	1.823
37	1.28	14.84	17.92	49.7	320.7	731	378	630	1.670
38	1.42	15.05	18.25	49.8	356.0	743	384	772	2.010
39	1.42	15.10	18.25	49.7	348.0	755	382	724	1.890
40	1.56	14.99	17.82	48.5	336.8	772	379	669	1.762
41	1.56	14.92	17.82	48.4	340.2	772	379	682	1.800

** Other data same as for Runs No. 24 to 41 in Table I.

Inlet circulating water temperature to cooler same as outlet circulating water temperature from heater.

23°30′ and 164°48′ from the top of the cycle. The volume of water accumulated by the tank between these two angles was calculated to be 55.4% of the piston displacement or 21.3 cu.in. The same increment was used as an approximation at the higher pulsation ratios.

Comparison of Heat-Transfer Results

Results are tabulated in Tables 1 and 2. Only runs with heater heat balances checking within 7% have been included. The Series II runs show an average of 1.8% more heat taken up by the water than given up by the steam if it were dry and saturated. Superheat in the steam may account for most of this discrepancy. The superheat in dry steam throttled from the supply pressure to the jacket pressure would have amounted to 3% of the latent heat. In practice this would have been reduced by any water passing through the steam separator and by heat losses in the outer steam jacket. Little difficulty was encountered in maintaining conditions in these runs, and the average deviation from the 1.8% average heat balance discrepancy was only 0.7%.

The Series I runs show an average of 3.2% less heat taken up by the water than given up by the steam, and this difference would be increased by allowance for superheat. Part of the discrepancy must be due to heat losses from the circulating water lines between thermowell stations. The average temperature difference for heat loss from these lines was five to ten times as great as in Series II. It was more difficult to control the runs in Series I, and this is reflected by an average deviation of 1.8% in the heat balances from the average heat balance.

Over-all coefficients of heat transfer for the inside tube area were calculated from the heat taken up by the circulating water and the log-mean temperature differences and are listed in Tables 1 and 2. The coefficients increased with increase in pulsation ratio.

The experimental inside water film coefficients, h_w*, were found by subtracting the predicted wall- and jacket-side resistances from the over-all resistance. A thermal conductivity of 34.6 B.t.u./(hr.)(sq.ft.)(° F./ft.) was used for the pipe wall. Condensing steam film coefficients were calculated from Equation (1) (7):

$$h_j = 0.95k_f\left(\frac{\rho^2_f g L}{\mu_f w}\right)^{1/3} \qquad (1)$$

The annular water film coefficients for the cooler were calculated from Carpenter's Figure 11 (2); the cooling water rate had been estimated by a heat balance over the cooler.

The inside water film coefficients observed for the heater at the two lowest pulsation ratios, 1.02 and 1.04, have been compared with those predicted for normal flow by Equation (2) (7):

$$h_w = 0.00391(1 + 0.0133t_f)\frac{G^{0.8}}{D^{0.2}} \qquad (2)$$

The coefficients for the most accurate set of runs, those of Series II heating, averaged only 1.2% above the predicted values. Those for Series I heating averaged 5.3% below the predicted values but would have been much closer if the heat transferred had been based upon the condensate instead of the circulating water.

The inside water film coefficients observed for the cooler at the two lowest pulsation ratios averaged 22% higher than predicted. This is much more than can be accounted for by experimental errors even though these admittedly were larger than for the heater runs. It is believed that an unusual degree of turbulence is responsible for the higher coefficients. The calming section is preceded by a pipe tee used as an elbow with the flow entering the run. Such a fitting should have an equivalent length of 60 pipe diam. (10) in determining pressure drop due to friction. The calming section is only 4 diam. long, and the cooler itself is only 46 diam. The 22% increase over the normal film coefficients for exchangers with adequate calming sections can easily be explained by the hundred per cent increase in the pressure drop.

The effect of the pulsation ratio on the observed inside film coefficients is shown in Figure 3. The observed coefficients have been expressed in terms of their ratios to the predicted values for steady flow with adequate calming sections to correct for variations in the water rate and temperature. The coefficients increase slowly at first and then more rapidly up to the pulsation ratio of 1.42. At this point the ratios of observed to predicted coefficients are 60 to 70% greater for all series than at pulsation ratios of 1.02 to 1.04. At still higher pulsation ratios poorer results were obtained, and the vibration of the equipment became excessive.

Comparison of Power Consumption

The gross power drawn by the pump's motor for each run is shown in Table 1. Considerable difficulty was experienced in reading the total power because the wattmeter needles oscillated as much as 25% above and below the average reading for each stroke of the pump. The value reported should be considered as an approximation since it is the sum of the averages of the high and low readings for the two meters. The values are erratic, but there appears to be a slight increase up to moderate pulsation ratios in each series of runs. A considerable and unexplained difference in power consumption was noted between the two series.

The gross power consumed is not a fair criterion for determining the effect of pulsations on the power consumption because of the large "no-load" losses of the pump and motor. The no-load losses, including the power to pump the greater part of the water through a by-pass which was throttled sufficiently to force a trickle of water through the exchanger, were found to be 1650 w. after Run 20 of Series I and 1140 w. after Run 41 of Series II. The authors cannot explain the difference of 500 w. between the two no-load losses but presume it to be related to the temperature of the water pumped, 75° C. in Series I compared with 15° C. in Series II.

If the net power consumption is calculated for each run using the above no-load values for Series I and Series II, the two lowest pulsation ratios average 725 w. in Series I and 770 w. in Series II. These net consumptions agree closely among themselves but are approximately 45% higher than predicted for the pressure-drop section alone using the friction factor curve for 1- to 12-in. commercial iron pipe (*10*). It is likely that the section acted as though it had "rough" walls since the Reynolds numbers were high and the ⅜-in. black-iron pipe had rusted.

The net power consumption as calculated here increases 10 to 30% between pulsation ratios of 1.02 or 1.04 and 1.28 or 1.42. This is a moderate increase for the resulting improvement in heat transfer. These values are presented with reservations in view of the assumptions as to no-load losses, the difficulty in reading the oscillating wattmeters, and the variation in water flow rate between runs. It should also be remembered that the net power consumptions are for isothermal pulsating flow in the pressure-drop section since the theoretical power consumption in the heat exchangers was less than two watts.

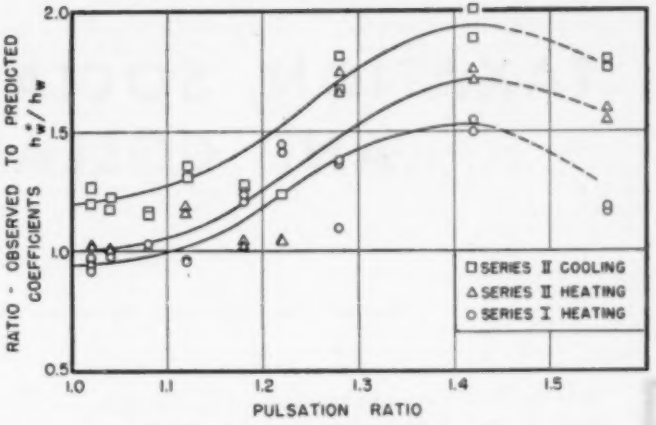

Fig. 3. Effect of pulsations on water film coefficients.

General Comment

The present results indicate that it should frequently be possible to boost the capacity of existing heat exchangers operating with turbulent flow of liquid inside tubes without excessive increase in power consumption by switching to reciprocating pumps with a controlled degree of dampening of the pulses. More work is needed to determine the optimum period and amplitude of the pulsations and their applicability to heat exchange with other liquids and with gases.

Notation

D = inside tube diameter, ft.

g = acceleration of gravity, ft./(sec.)(sec.)

G = mass velocity, lb./(sq.ft.)(hr.)

h_j = predicted film coefficient of heat transfer on jacket side, B.t.u./(sq.ft.)(hr.)(° F.)

h_w = predicted film coefficient of heat transfer inside tube

h_w^* = observed film coefficient of heat transfer inside tube

k_f = thermal conductivity of condensate at average condensate film temperature, B.t.u./(sq.ft.)(hr.)(° F./ft.)

L = length of heat-transfer tube, ft.

t_f = average temperature of inside water film, ° F.

U = over-all coefficient of heat tranfer, B.t.u./(sq.ft.)(hr.)(° F.)

w = weight of condensate per tube, lb./hr.

μ_f = viscosity of condensate at average condensate film temperature, lb./(ft.)(hr.)

ρ_f = density of condensate at average condensate film temperature, lb./(cu.ft.)

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TAXATION, SOCIALIZATION AND COLLAPSE

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. . . The winner of the Professional Progress Award in Chemical Engineering for 1951 speaks out from a technical viewpoint on some problems in economics and American mores . . .

THE people of the United States today enjoy the highest standard of living the world has ever known; no other country has even approached us in this respect. To express this another way, the average American is able to obtain far more consumer goods and useful services than the average citizen of any other country. This is largely because the average American worker is provided with tools which enable him to produce more consumer goods and useful services than the average worker of any other nation.

The level of national employment in itself is not a measure of living standard. In our own country, if all the tools of production were destroyed, we would be kept busy with our hands trying to produce enough from the earth to feed and clothe ourselves. There would be poverty and starvation, but certainly no unemployment. On the other hand, the level of national employment *at maximum production of useful goods and services* is an indirect measure of living standard.

Our industrial growth during the past 50 years has been great; but if present trends are permitted to continue, within the next decade a decline in the national production of useful goods and services can be expected followed by complete socialization and collapse of the living standard to a level some place between that in Britain and the United States today. As a matter of fact, our country already is in the transition stage to socialism.

The underlying causes for this discouraging future are twofold. First, it appears that our government is dedicated to a program of inflating our money volume at such a rate that all the money cannot be used to effect a corresponding increase in national productivity. This is being done by expanding the public debt through deficit spending. In the past decade this has resulted in a reduction of about 47 per cent in the purchasing power of the dollar. It has had a devastating effect on industry because of its effect on depreciation reserves. When a new tool of production is installed, a part of the income from this investment is placed in reserve, in accordance with traditional accounting practice. This is done so that the tool can be replaced when it is worn out. Such reserves are based on the original cost of the tool rather than the replacement cost. So, after ten years of continual inflation, the reserve is only about half enough to pay for replacing the old tool. This is serious, but there are many more ill effects of inflation on our economy. However, instead of discussing inflation further, my remarks here will be directed to the second underlying cause of our serious plight today which is the trend of gradually increasing the income tax rates. This trend is destroying incentive and siphoning off risk capital needed for investment in new tools of production.

C. G. KIRKBRIDE, vice-president and director of Houdry Process Corp., gives us in the accompanying article his own State of the Union address. The winner of this year's Professional Progress Award in Chemical Engineering has been associated with the Standard Oil Company of Indiana, Pan American Refining Corp., Magnolia Petroleum Co., and in the field of education has been professor of chemical engineering at A. & M. College of Texas. He has been active on A.I.Ch.E. committees and at present is a Director with a term expiring in 1952. A graduate of the University of Michigan with an M.S. in chemical engineering, Kirkbride is the author of several papers on heat transfer, multicomponent fractionation and phase equilibria.

When the last source of risk capital has been eliminated by our lawmakers, private investment in new tools of production or, for that matter, in replacement of existing tools will be insignificant. The worn-out tools merely will be patched up and kept in operation as long as they can be held together, just as has been done in Britain. To be sure, their productivity will decline, which will result in a loss in our living standard again as in the case of Britain. Even so, there is no incentive to incur the risk of investing in new tools if the increase in income will be taken by taxes. Under these conditions, of course, there will be no such thing as obsolescence, because technological development will have ceased. Once this situation exists the government will be able easily to point to the failure of private enterprise to provide the living standard demanded by the people. Certainly the basic causes for failure will have been barriers of taxation and inflation which were created by the lawmakers. Even so, regardless of the cause, one will have to admit then that private enterprise has failed. Obviously, the stage will then be set for complete socialization of industry. This is quite a discouraging prediction but it certainly will come to pass unless the people of this country demand a revision in the tax laws so that individual incentive is protected.

I plant first to discuss some accomplishments attained by the American way of life and the factors that stimulated these accomplishments. Then I shall review briefly the situation in Great Britain in an effort to point out

why its economy is in so sad a state of decay. Following that I want to register a warning lest we degenerate into a similar state of social and economic decay. Finally, I shall propose changes in our tax laws in order to avoid economic collapse.

American Way of Life. America has had historically a high investment economy. During the 60-year period between 1869 and 1929 the average private expenditure for producers' durable goods (tools of production) increased on the average of almost 4½ per cent a year over the preceding year. In other words, the average amount invested each year in tools of production, measured in 1929 dollars, increased almost 13-fold between 1869 and 1929. This rate of increase in investment in tools of production has permitted a huge increase in the national production of useful goods and services per worker. The industrial production per worker in 1950 was 5.3 times that in 1889 even though there was a substantial reduction in the work-week.

Dexter M. Keezer and Associates (*2*) point out that our standard of living has tripled during the past century, while the work-week has been reduced almost 50 per cent. This was made possible only because the American workers have been provided with more and better tools which have resulted in greater and more efficient production with less effort on the part of the workers. Each worker uses 30 times as much mechanical energy as he did a century ago. The investment in tools of production and the availability of cheap power have permitted a 17-fold increase in the nation's production during the past century.

Technological Development

The rapid growth in agricultural as well as industrial productivity has been a result of technological development. Research and development played a major role in creating new tools of production. In particular, the creation of entirely new industries has provided such a demand for labor that labor-saving devices could be adopted in practically all industries without causing unemployment. This is a dynamic economy when new enterprises, new industries or expansions in existing establishments are being brought about so that more and more labor is required. Only in a dynamic economy can labor-saving tools of production be installed without creating unemployment. In a static economy there is nothing new being industrialized to absorb labor. The resultant state of unemployment has been one of the many serious problems in Britain.

Research and development are creators of new frontiers in industry which demand more and more labor. Prior to World War I, lone inventors were quite common. They were successful in creating new enterprises many of which have grown into giant industries. At that time the application of scientific knowledge to the production of useful goods and services had not been exploited significantly. Therefore, it was possible for a lone inventor, who had a broad grasp of scientific information, to apply this knowledge for the benefit of society. This was what one might call scratching the surface of science. It was not too costly to attain outstanding results. However, after the turn of the century it became more and more difficult for a lone inventor to succeed because the surface of science had been scratched so thoroughly that it really was quite well polished.

Organized research and development began to grow rapidly after World War I. Instead of lone inventors, teams of inventors worked together. By this procedure it was possible to drill beneath the surface of science by the application of scientific theory as the guiding light. It was more costly than in the case of the lone inventor because more expensive personnel and scientific instruments were needed in the unfolding of science below the surface. Furthermore, the deeper research teams go, the more costly it is. Even so, organized research has paid off to those who have been willing to risk investment of their savings.

Twenty Years of Research

There was a five-fold increase in private industrial research and development between 1930 and 1950. Many new industries have been created which demand more labor. Furthermore, the possibilities are unlimited for research and development to increase living standards beyond anything imaginable today. As an example of what can be done, the Du Pont Co. has stated that 60 per cent of its sales in 1950 came from products which were unknown or in the research and development stage in 1940. It is expected in 1960 that its sales will come from products 60 per cent of which were unknown or were in the research and development stage last year. No doubt this expectation is predicated upon the hope that tax laws will not prevent such expansion.

The miraculous rise in our standard of living was accomplished under an economic system which the economists have called "Capitalism." There are many variations of capitalistic systems, however, so this name does not adequately describe the American way of life; our system of capitalism has been quite different from the British system of capitalism. *Ours is an incentive system that stimulates initiative only in a competitive atmosphere of individual freedom.*

Under this system, technological development has flourished. Nevertheless, the industrial growth that provided our present high standard of living would never have taken place had it not been for the fact that people had saved and were willing to risk their savings on investments in new tools of production. Risk capital is therefore equally essential as technological development. In addition to these two elements there must be an incentive to invest risk capital in a new hazardous enterprise. There must be a reward for success which justifies the risk. Investment in new tools of production comes only out of savings, (that part of production which is not consumed). The incentive to divert savings into this channel is that the production of consumer goods can be increased during the period of the life of the new tool. Unless this tool can be used successfully for its intended purpose over a long enough period of time, it will not produce sufficient consumer goods to pay for itself. Thus, investments in tools of production involve risk, because plans do not always materialize as anticipated. Nevertheless, a progressive economy entails the risk of trying new methods. The more progressive the economy is, the more the risk involved in a given investment because the greater the chances will be that a better method will be found at an early date to make the existing method obsolete. A socialistic economy cannot eliminate risk without eliminating progress because security and progress do not go hand in hand. There is a sharp distinction between security and a feeling of security. The very life of our economy is dependent upon technological development, risk capital, and incentive. Competition is the life blood which maintains the economic health.

A Look at Britain. In years gone by it was not possible to refute arguments in support of socialism as opposed to the American way of life except by resort to economic theory. Today, however, this is no longer necessary because Britain affords an excellent direct comparison. Lest there be the misconception that the Tory government of Britain is not socialistic here is a comment from the London Economist of April 26, 1947:

> The fact is that British industrialists, under the deliberate leadership of the Tory Party in its Baldwin-Chamberlin era, have become distinguishable from the British Socialists only by the

fact that they still believe in private profits. Both believe in "organizing" industry; both believe in protecting it, when organized, against any competition, either from foreigners or from native newcomers; both believe in standard prices for what they sell; both unite in condemning competition, the one as "wasteful" the other as "destructive." If free, competitive, private-enterprise capitalism is to continue to exist, not throughout the national economy, but in any part of it, then it needs rescuing from the capitalists fully as much as from the Socialists.

Quotations by the Tory Party confirm this official conclusion by the Economist. Therefore the period of socialistic practice in Britain includes periods during which the Tory Party as well as the Labor Party was in power. Consequently it would be well to look at the situation in England today and retrace the history of evolution of its present economy. Possibly in putting our finger on their mistakes we can avoid such in our own economy. Before proceeding, however, it should be emphasized that my statements are not intended, in any way, to be a criticism of the British people. This discussion of the British economy is intended to be completely objective. Also, in order to avoid any impression of prejudice, these remarks on Britain have been drawn from British writers with the one exception of a résumé of conclusions by the French economist André Siegfried.

Recently, Sir Ewart Smith (*8*) presented a comparison of the annual industrial production per worker in Britain with that in the United States. In 1889 the industrial production per worker was about the same in each country. Each year since then industrial production per worker in Britain has increased on the average of only about half the rate of increase in the United States. Consequently, because of this difference the average annual industrial production per worker in the United States in 1950 was about 2½ times that in Britain.

Also another British investigator, L. Rostas (*6*) presented a comparison of industrial production in Britain in 1935 with that in the United States in 1937. He concluded that the physical production in the United States per worker averaged about 2.3 times that in Britain which is in excellent agreement with Sir Ewart. Since the average work week in Britain in 1935 was about 22 per cent longer than that in the United States in 1937, our productivity per man-hour was more than 2.8 times that in Britain. A comparison of a few specific industries shows that the ratio of the production per worker in the United States to that in Britain was 4 to 1 in the iron and steel industry; 4.19 to 1 in the motor car industry; 4.82 to 1 in manufacturing radio sets; 2.66 to 1 in the manufacture of rubber tires; 1.60 to 1 in wheat milling, and 1.3 to 1 in cotton weaving.

In addition to the studies by Smith and Rostas, there are reports of a number of investigating committees which were appointed by the British Labor government.

Tools and Production

The economist, George Terborgh (*3*) presented a digest in 1948 of 11 reports of the working parties, as well as of two reports of special investigations of the British coal industry. In addition to showing differences in productivity per worker of the same order of magnitude as shown by Smith and Rostas, the working party reports conclude that the cause of these differences is due to inferior tools of production in Britain compared with those in the United States.

It is not surprising that the tools of production in Britain are inferior to those in the United States when in many cases replacement of worn-out and obsolete tools ceased around the turn of the century. A survey in 1930 of the cotton textile industry showed that, with the exception of only two operations, between 55 per cent and 77 per cent of the equipment was installed prior to 1910. Furthermore, the report by the working party stated that since 1930 there has been little replacement in equipment and only five new spinning mills erected in the 25-year period prior to its reports. In America 70 per cent of the looms are automatic compared with 6 per cent in Britain. Buildings in all industries were often more than a century old but even the later ones were poorly arranged.

There is no question but that the differences in productivity per worker in Britain and the United States is primarily a result of the difference in extent and efficiency of the respective tools of production. Curiously enough, however, this is known by the British, and for that matter the thinking people of Britain knew it even before the turn of the century. The literature has been full of warnings since 1886. The report of the Commission of Enquiry Into the Economic Depression of 1886 left no doubt about it. It states, "We are no longer alone. More active rivals with better equipment are springing up and leaving us behind." The Blue Books since then have repeatedly given the same grave warnings. Along the same line the London Economist of Aug. 4, 1945, states: "The public has in recent months waked up to the fact that the whole wealth-creating mechanism of the British community is badly in need of a drastic overhaul."

It is apparent therefore that the important cause of the difference in living standards between Britain and the United States is a result of technological stagnation in Britain. But why should this have happened in Britain? From the time in 1774 when Watt and Boulton began to manufacture steam engines the British standard of living increased rapidly but leveled off after about 1870. The Victorian era was the zenith of prosperity and power in Britain. It was founded on utilizing the steam engine. The keystone industries were coal, iron and steel, and textiles. These were established by technological development.

But again why? Why should the British economy fail when it was doing so well up to the turn of the century? I am convinced that the basic reason for her (Britain's) failure is an unsound attitude or philosophy caused by a lack of competition and individual incentive. The symptoms of her disease were manifesting themselves during the height of prosperity between 1860 and 1870. Then between 1870 and 1900 the symptoms became more apparent. Those symptoms today are open sores. Furthermore, this writer believes that the disease can be cured only by a radical change in attitude. Pouring billions of American tax payers' dollars into Britain certainly is not the cure. It would be well to review this because I think that today in the United States we have many symptoms that were apparent in Britain at the turn of the century. An important difference however is that the disease in America appears to be developing somewhat faster than it did in Britain.

According to the French economist André Siegfried (*7*), British industry had essentially no competition prior to about 1860. Her mines enjoyed a quasi-monopoly and as long as coal was the only industrial fuel her industry was unrivaled. During this period an attitude developed within Britain toward internal competition. There was no need for British industries to compete among themselves. The world was their market and they had no competitors outside of Britain. The pie was plenty big enough, so why not agree to cut it up and sit down and eat it like true English gentlemen? It was at that time that cartels were born. There was a gentleman's agreement between management, labor, and government to prevent competition within Britain. If anyone got a bright idea on reducing manufacturing costs and then reducing prices in order to get business he was usually liquidated either by government or labor. There was no anti-trust law in Britain and furthermore there is none today.

During this period of British monopoly, management developed inertia and complacency. There was really no incentive to replace old equipment because the margin of profit was so great that new equipment would make little difference, and besides it would cost money.

Vital Role of Coal

In 1896 Stanley Jevons (*1*) predicted that the situation today in Britain would come to pass. He attributed Britain's position to its monopoly on coal mining. He pointed out that coal is capital and it was not being replaced. As the coal mines became depleted he visualized that the cost of coal would increase until a point would be reached at which manufacturing would not be economical. Because of this he said Britain would lose her monopoly which would bring on unemployment and industrial decay.

The coal supply was not exhausted, but the monopoly was lost because British industry did not replace its worn-out and obsolete tools of production. Britain should have made an effort at the time of Stanley Jesons' warning in 1896 to improve her situation. But she rested on her laurels and all that the monopoly entailed.

Siegfried stated that Britain really believed that she was competing internationally under free trade. However, she did not encounter a dangerous rival until she met the Germany of Kaiser William II. She had developed an over-confidence to such an extent that all foreigners were second raters living on a plane below her. As a result, the qualities of energy and determination commonly attributed to the British were lost from business in England. The inherited habits of wealth and power resulted in an aristocratic manner, together with a belief in the divine right of the British.

At the close of the 19th century a new generation was born with ideas of abundance and glory. They became accustomed to easy money for they believed that success was their due. They developed habits of the statutory minimum for work and the statutory maximum for pleasure and leisure. Out of these defects came a philosophy of life—original, charming, and comfortable. Why should one strain himself in crude economic pursuit when overwork used up his strength and sapped his vitality? So they looked for results without effort—something for nothing if you please—and then came to consider it unfair competition when faced with those who denied themselves in order to succeed.

Also because of the lack of competition and financial incentive, applied research and development did not flourish in Britain. A vicious cycle develops with technological stagnation—no new tools of production are being purchased, which leads to a cessation of applied research and development and this in turn leads to the conclusion that the tools of production in use are as good as the ones available. Britain has been a big contributor in fundamental research but she has devoted insufficient attention to applied research and development. It appears that they spend only about 10 per cent of the amount we spend on private industrial research and development.

Of course, labor-saving devices and labor-saving processes were resisted by labor. But surprisingly as it may seem, they were also resisted by management because such developments resulted in the necessity of greater investment in tools of production. When the margin of profit is large, as it can be under a monopoly, there is little if any incentive to risk investment in new tools of production.

Of course, it is easily understood why labor would resist labor-saving devices under the circumstances. The British economy since before 1870 has been little more than static. Under such conditions labor-saving devices would throw labor out of work. The cure for this is to expand applied research and development to bring forth new enterprises and new industries. These would absorb labor at such a rate that labor-saving devices would be required to permit the expansion of the new enterprises and new industries. However, a backward management is rarely interested in applied research and development.

Another reason why so little applied research and development has been done in Britain is the small number of those trained in engineering or applied science. Sir Ewart (*7*) concluded that this is the fundamental cause for the differences in productivity and living standards of Britain and the United States. The number of engineers per unit population produced each year in the United States is about four times that in Britain. He states:

> It is the writer's belief that our inferiority in this respect has not only slowed up the rate and efficiency with which scientific and technological knowledge is now being applied throughout industry in this country, but has also led to a lower over-all standard of scientific approach and understanding in the whole field of management — industrial, economic, and political—as affecting industrial affairs.

He also pointed out that for any given level of human energy and ability, the rate at which productivity will increase depends primarily upon the evolution and application of new technical knowledge. Also it follows logically that the availability of engineers will play a major role in determining the rate of increase of the productivity and living standard of Britain, or the United States for that matter. Even so, this develops into a vicious cycle—a backward management will not employ engineers, which leads to students not selecting an engineering curriculum, and this leads to too few engineers to guide the backward management, and finally to take on managerial duties.

The little incentive existing in Britain was thoroughly debilitated about a quarter of a century ago by high progressive tax rates on personal incomes and an excessive tax rate on corporate incomes. This was important toward finishing the job of wrecking the British economy but the job was well along before the tax blow was delivered.

Beware of Destruction of Incentive System. Britain today is faced with a highly advanced case of technological stagnation and there is a great deal of similarity between the symptoms of this disease in Britain as manifested between 1870 and 1914 and in the United States today. Over-confidence, something for nothing, success their due, habit of extending leisure time, complacency toward cold facts, and a mania for security are evident in the United States today just as they were in Britain between 1870 and 1914. *It is a disease caused by lack of individual incentive.* Normally people do not want something for nothing. They really want to be useful.

Social decay and economic stagnation are slow reactions. There may be several generations between the cause and the effect although at the rate we are going I doubt if it will be more than 10 to 15 years before the disease of technological stagnation forces this country into socialism and economic decay. The causes for the disease in the United States are different from those in Britain but the result will be the same. Unless individual financial incentive to produce more is protected and encouraged we too will have technological stagnation followed by socialization and collapse of our living standard. Even now, our industries are not up to date with the level of advancement in technological development. George Terborgh (*9*) states, "This country too has its quota of mechanical zombies." This situation can be expected to be more pronounced as our lawmakers pursue the present course of taxation and inflation.

The system of progressive taxation of personal incomes as *applied today* involves increasing the *percentage* tax on

income as income increases. Therefore, as applied today, progressive taxation is based on "ability to pay." It is argued by certain advisers to our lawmakers, that as long as any group of individuals has left, after taxes, more than another group, its capacity to pay has not been exhausted by taxation. This principle implies leveling off of income after taxes to the point necessary to collect the taxes needed by the government. The principle of taxing *in proportion* to the income received under the protection of the state was advocated by Adam Smith but as progressive taxation is applied today it is really a progressive rate of taxation. This is truly a socialistic philosophy which destroys incentive to excel or to produce more. It is better to take life easy, under such circumstances, because additional production would be taken as taxes.

The principle of "ability to pay" not only eliminates incentive but also the personal savings which would otherwise be possible. In the past, these personal savings have been an important source of risk capital. Many new hazardous enterprises which have developed into large industries are therefore not being initiated because of the lack of both financial incentive and risk capital. The full impact of this will not show up for perhaps 10 to 15 years.

According to Roswel Magill (*4*), the cost of government has become so great that in order to obtain an additional 10 billion dollars over and above the tax burden today it would require a 100 per cent tax rate on all taxable incomes of more than $4,000 a year. Additional taxes will, therefore, have to be obtained from lower income brackets. As the situation existed in 1948 (*4*), a man with a wife and one child having an income of $3,500 a year had to pay on the average $233 income tax; but he also paid $675 in hidden taxes. There is no such thing as something for nothing. *The entire tax burden must be supported by the consumer.* The progressive tax laws have leveled off incomes but the differences in consumption between low and high income brackets have not been changed significantly. Hence, the tax burden is really distributed over all income brackets because of the hidden taxes.

Corporate Income Tax and U. S. Economy

The policies of our lawmakers with regard to corporate income tax rates is even more detrimental to our economy. During 1913-35 the tax rate increased from 1 per cent to 13.75 per cent. Then it was increased to 19 per cent in 1938 and 40 per cent plus an excess profits tax during the last war. In 1946 it was reduced to 38 per cent but in 1950 it was increased to 45 per cent plus an excess profits tax which might increase the rate to 62 per cent. In 1951 the tax rate was increased to 52 per cent plus an excess profits tax that may increase the rate to 70 per cent. It is apparent that the lawmakers are following a policy of increasing the corporate tax rate over the period of years. Based on the performance to date there is no reason to believe that they will not continue this trend.

It may be argued that the period of the past 15 years has been one of great expansion in industry. Hence, the high tax rates have not seemed to hinder progress. The fact is, however, that this was also the period of the greatest expansion in private industrial research and development; and despite these rates our research and development were able to bring about progress. Nevertheless, the load now is so great that it is becoming increasingly difficult to develop new tools of production that can be justified economically.

The question may be asked, "Why are our lawmakers following this unsound tax policy?" The answer is that they are being advised by certain theoretical economists who are proponents of the "purchasing power" and "mature economy" theories. Each Federal bureau has its quota of these proponents. Also, a number of them openly advocate an authoritarian-type government such as socialism.

Following the stock market crash in 1929, investment in tools of production dried up and remained so for several years. These economists concluded that the United States had reached a mature economy; and that in the future little investment in tools of production would be required to maintain the fully developed industrial plants at optimum productivity. They felt that no new large industries could be expected to advance the economy in the future. Apparently these economists have never heard of the United States Commissioner of Patents who committed suicide in 1839 because all important inventions had been made.

These economists sold our lawmakers in the 1930's on the following program (*5*):

- To tax savings out of existence by high corporate income tax rates and by high progressive taxes on personal incomes.
- To stimulate consumer demand by distribution of the revenue from taxes to increase consumer purchasing power. This would create a "high consumtion" as opposed to a "high investment" economy.

Keezer and Associates (*2*) point out quite vividly that the United States did not return to full employment until war production brought it about in 1942. An important reason for this was that as the Federal government pumped consumer purchasing power into the economy, it simultaneously destroyed confidence in the future which discouraged private investment in tools of production. Also, the tax policies reduced the incentive to risk investing in new tools of production. Since about one third of the industrial workers of the nation are employed in the capital goods industries which produce the tools of production, the pump-priming episodes prior to 1942 did not put a high percentage of these people to work. As Keezer emphasizes, the United States has enjoyed prosperity only during periods of high investment.

As pointed out earlier, the effect of our present Federal tax policies is the destruction of incentive and the elimination of risk capital. Recently, this writer had occasion to present an engineering economics study to a group of executives of a large oil company. This study involved the installation in its refinery of two new processes which we had under development in our laboratories. The total investment was about $15,000,000. On a tax-free basis the investment would pay for itself in about two years. Hence, this is not too great a risk if the invested money could be returned in two years. However, this oil company is operating in the "pseudo" excess-profits bracket which would result in 82 per cent of each dollar of profits from the new investment being taken by income taxes. Therefore, instead of the proposed investment paying for itself in two years it would require more than 11 years. This places the proposal in an entirely different light. The risk is too great because of the possibilities that a better process might be developed within the next three or four years that would make the proposed process obsolete. There would be little hope for profit in such a proposed investment. Furthermore, the chances are good that a large part of the money invested might be lost.

This situation places a tremendous barrier in the path of progress of research and development. A research and development organization must be a bunch of magicians to overcome so serious a handicap as imposed by our income tax laws. It becomes more and more difficult to create something new which can pay for itself in a sufficiently short time so that risk is within reason.

Our corporate income tax policies are

preventing many new tools of production now in research and development laboratories from being commercialized. The tax collectors, as well as labor are actually losing because of the short-sighted policies in a tax structure that discourage private investments in these new ventures. If the tax structure were not a barrier to the commercialization of these new tools of production, there would be many new industries created which would provide unlimited opportunities for labor.

Unless our tax structure is changed radically, the time will come—and soon—when very little research and development can be justified. Were it not for the hope that our lawmakers will soon recognize their errors and correct the adverse features of the tax structure our industrial research and development budgets would be only a small fraction of their size today. The incentive for research and development and the competition between private research and development organizations must not be hindered in any way. Ours is a technological economy and nothing should be permitted to discourage its progress.

Limitations on rates of amortization or depreciation imposed by the Department of Internal Revenue is probably the most destructive of the adverse features of our tax structure. The over-all weighted average of the amortization rates permitted by the government on fixed assets of American corporations is less than 3 per cent a year which implies an average service life of more than 33 years. The average amortization rate for manufacturing corporations alone is 3.7 per cent or an implied average service life of 27 years. This means that the money invested in these fixed assets cannot be returned until the implied service life is completed. This is most discouraging to investors because obsolescence is a danger which such rates do not consider.

Obsolescence depends on how successful our competitors are, or for that matter how successful we are, in applied research and development. The more emphasis there is in the field of research and development the more probable it is that a new and better tool of production will be commercialized at an early date with which the existing tool cannot compete successfully. When this happens, we are forced by competition or by the incentive for greater profits to replace the existing investment with the new tool of production. The useful life of the old tool will have come to an abrupt end at that time.

The only purpose of investing in a tool of production is that it can be used successfully to produce consumer goods or useful services. Other than that it has little value. *Therefore, from a practical standpoint no profit has been made on any tool of production until the tool has produced sufficient consumer goods or useful services to pay for itself.* To express this another way, the total net profit, after taxes but before any allowance for depreciation, from a tool of production must exceed the investment cost for this tool before the management can say definitely that it has made a profit from this investment. Obsolescence might occur before the investment has been fully amortized.

I realize fully that this concept is opposed to the conventional accounting procedure. But the conventional procedure of estimating the useful life of a tool of production and amortizing the investment over this life-period has several serious weaknesses. This procedure was established more than a century ago when there was little emphasis on research and development. Therefore, it does not consider obsolescence properly. It does not take into account adequately the replacement cost of the tool as affected by inflation. It confuses capital and profit.

The procedure of amortizing a tool of production over its estimated life is anything but conservative because of the uncertainty with regard to obsolescence. Of course, one purpose of this historical accounting method is to minimize unaccounted for assets which result after fully amortizing a tool of production that still has useful life. Nevertheless, this could be handled by a procedure which does not confuse capital and profits.

At least part of any profit shown from a tool of production is artificial until the tool is completely amortized. The amount on the books that is not amortized is capital. Therefore, the total profit attributed to this tool of production is erroneously on the high side by the amount on the books that is not amortized. This amount of profit can be shown only because a capital asset is claimed which would not be at all valid if obsolescence occurred before the end of the estimated useful life.

Whether or not investment should be made in a new tool of production is determined by engineering economics almost always on the basis of how soon the tool will pay for itself with the expected profit. The limitations on the time for paying off the investment will depend on the purpose of the tool the availability of risk capital, business prospects, possibilities of obsolescence, and other factors.

However, once an investment is made, the engineering economics for operating the tool of production must be based on cost exclusive of the original investment cost. This is forced by competition. Regardless of how much of the original estimated life is left, or the depreciation charges, these costs have no influence on the situation in meeting competition because the fixed costs will go on whether the tool of production is operated or not. It is the incremental or variable costs which dictate the economic conclusions under such conditions. Therefore, because of the possibilities of obsolescence, the investment risk is reduced to the minimum by amortizing the investment in a tool of production as soon as possible.

Therefore from the standpoint of fairness, as well as protection of incentive, no limitations whatever should be imposed by the Federal government on rates of amortization and my thesis is that the Federal government is indulging in an unsound practice by dictating such limitations.

Because of the great uncertainty with regard to obsolescence in a dynamic economy in which so much research and development are being done, each management should have the freedom of establishing the rate at which its investment should be amortized. Each management is in a far better position to appraise the risks it is taking; and since each is responsible for the investment of its corporate funds, management should have the freedom of setting the rates of amortization.

Of course, the reason the government does this is so it can participate in the fictitious profits which in reality have not been made. If the government collected more taxes from a given investment by this procedure one could understand why it is so avid in grabbing taxes on profits before the profits are made, even though the concept is unsound from the viewpoint of engineer-

C. G. KIRKBRIDE

Award address was made to Institute members Tuesday morning.

ing economics. The facts are, however, that it will collect the same amount of taxes during its dictated period of amortization because only 100 per cent of the investment cost is amortized or depreciated.

This can be shown by a simple example. An enterprise makes an investment of $10,000,000 in a new tool of production. The income from this before taxes and depreciation is $4,000,000 a year. The Department of Internal Revenue will allow a depreciation rate of only 10 per cent a year and for the sake of simplicity one can assume that 50 cents of each dollar of net profits, after allowance for depreciation, is taken as taxes. On this basis the amount of taxes paid during the ten-year depreciation period, as dictated by the government, would be $1,500,000 a year or a total of $15,000,000 for the entire 10-year period. The investors would get their money back in four years because of the $1,000,000 a year allowance for depreciation plus the $1,500,000 of artificial profits after taxes.

Now assume that a sound engineering procedure is permited by the government so that no profits are shown until the investment cost is paid. In this case, the investment will pay for itself in two and a half years during which time no artificial profits are shown and no taxes are paid. Real profits show up after this at $4,000,000 a year and the taxes paid are $2,000,000 a year compared with $1,500,000 a year in the previous case. There remains seven and a half years on our original ten-year basis and it is evident that at $2,000,000 a year the total tax paid is $15,000,000 or exactly the same as when the government imposed an unsound procedure of depreciation. The only differences were that the people who invested the original $10,000,000 got it back in two and a half years instead of four years; the government waited two and a half years before it began to collect the $15,000,000 in taxes; and no profit was shown for two and a half years. Certainly this is not too much consideration to give people as an inducement to risk their $10,000,000 in the investment. In all fairness there should be no profits or taxes before the investment pays for itself.

In addition to the destruction of incentive by our corporate income tax laws, our lawmakers already have reduced individual incentive to a low level by the progressive personal income tax laws. Also, not only the incentive has been debilitated but also this source of risk capital has been thoroughly undermined. In years gone by one of the most important sources of risk capital for investment in common stocks was from savings of people with incomes of $5,000 a year and more. However, this source has been almost dried up by the personal income tax laws. That amount of saving which is left is invested in secure ventures such as insurance, annuities, and savings accounts. The reason for this is that there is little financial incentive to take the chance of increasing one's income by investing in a risky proposition if any increase in income would be taken largely as taxes.

The objective for a sound economic policy is full employment at maximum productivity of useful goods and services. To attain this we must protect and encourage individual incentives. Vigorous competition must be maintained because this is the stimulus to incentive. Our tax laws are well along toward eliminating the incentive from our economic system. They are in need of a complete overhauling before we get too far into technological stagnation. Once this disease gets a hold on our country it would take generations to overcome the unsound attitudes. On the other hand, the basic attitudes and philosophies required for a healthy incentive system can be destroyed within a generation.

Proposed Policies

First Change: Immediate elimination in our tax structure of all limitations on the rate at which investments in tools of production are amortized or depreciated. This would not affect the total taxes paid. It merely shows a little consideration to those who invest in tools of production by letting them get their money back before the avid grab for taxes and profits is effected.

Second Change: The sorely needed scrapping of the corporate income tax. It is unsound to set up a tax barrier that tends in any way to discourage investment in new tools of production. This tax is a form of poison which reacts to kill incentive. Small doses can be administered without ill effects showing up immediately. However, it is not a sound principle to administer small doses of poison just because the patient will not die. We need the highest level of health that can be had.

Third Change: Elimination of the progressive features of the personal income tax laws. This is vicious in killing incentive as well as siphoning off risk capital needed to finance new hazardous enterprises.

Fourth Change: Initiation of a sales tax in place of the income tax for raising Federal revenue; this to be carried out simultaneously with the first three steps. The advantage of this is that hidden taxes would be reduced to a nominal amount. Each person then would know how much taxes he is paying and whether he feels he is getting value for his taxes. The average family of three in 1948 with an annual income of $3,500 did not realize that 19.3 per cent of its income was paid out for hidden taxes. It knew only that 6.7 per cent was paid for income taxes. Bringing taxes out into the open would place a check on the government which undoubtedly would result in less waste of the tax payers' money. Furthermore, the sales tax would not destroy incentive to produce more consumer goods and useful services.

In closing, the following paragraph is quoted from the book, "Making Capitalism Work." (*2*); the word "incentive" has been substituted for the word "capitalistic" and the phrase "the incentive system" for the word "capitalism."

—Americans will live far better under a thriving incentive system than under any possible scheme of state socialism. By its very nature, socialism tends to slow down industrial progress. Its emphasis is on security and equality in the distribution of income rather than on a drive to create income. The incentive system, if allowed to operate smoothly, calls forth a maximum degree of individual initiative, thus promoting a rapid advance of living standards. In a word, the welfare state as thus far developed, concentrates on dividing up the pie more equally, rather than enlarging the pie. The incentive system operates to make the pie grow bigger. By producing more products and getting them distributed more broadly and more steadily, private enterprise under the incentive system can contribute a greater measure of welfare than any other system yet devised.

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Award address given by C. G. Kirkbride at the A.I.Ch.E. Meeting in Atlantic City, Dec. 2-5, 1951.

ANNUAL THESIS INDEX

ABSORPTION

"COLLECTION OF AEROSOL PARTICLES BY ATOMIZED SPRAYS."—R. B. Feild—October, 1951.
Professor H. F. Johnstone, *University of Illinois*, 85 pp. 2 copies and abstract available. Work continuing.

"THE DIFFUSION OF A DISSOCIATING GAS AT MODERATE PRESSURE."—David K. Eads—September, 1951.
Professor John R. Bowman, *University of Pittsburgh*, 105 pp. 4 copies and abstract and conclusions available. Work continuing.

"FACTORS AFFECTING BUBBLE PLATE EFFICIENCY IN GAS ABSORPTION."—Lun-Lee Yuan—June, 1951.
Professor R. C. Kintner, *Illinois Institute of Technology*, 150 pp. 1 copy and abstract available. Work continuing.

"LIQUID-SIDE RESISTANCE IN GAS ABSORPTION WITH AND WITHOUT CHEMICAL REACTION."—D. W. Peaceman—August, 1951.
Professor J. E. Vivian, *Massachusetts Institute of Technology*, 426 pp. None available. Photostat 35¢ page. Microfilm $0.04 page. Work continuing.

"LIQUID TURBULENCE IN A GAS-LIQUID ABSORPTION SYSTEM."—Alexander A. McLeod—May, 1951.
Professor C. C. Monrad, *Carnegie Institute of Technology*, 141 pp. 1 copy available. Work continuing.

"SCALE-UP OF PACKED ABSORPTION TOWERS; CORRELATION OF TRANSFER COEFFICIENTS FROM WETTED-WALL COLUMNS, PLANE SURFACES AND PACKED TOWERS FOR VAPORIZATION PROCESSES."—Roy J. Stanclift, Jr.
Professor J. O. Maloney, *University of Kansas*, 326 pp. 1 copy available. Work continuing.

ADSORPTION

"ADSORPTION KINETICS IN FIXED BEDS."—V. C. Thaker—November, 1951.
Professor Harding Bliss, *Yale University*, 232 pp. 1 copy available. Work continuing.

"DRYING OF AIR IN FIXED BEDS."—Lee C. Eagleton—June, 1951.
Professor Harding Bliss, *Yale University*, 229 pp. 1 copy available. Work continuing.

EDITOR'S NOTE

This is our first attempt to classify Ph.D. theses in chemical engineering. In an effort to make this list serviceable to you we have grouped under main headings. Since this was done entirely from titles, some classifications may not be correct. As an example: A study on the kinetics of ion exchange could be listed under "Kinetics," or "Ion Exchange." Another example: it was sometimes difficult to decide whether a title should fall under the heading of heat transfer or mass transfer if both phenomena seemed to be under investigation. Hence, the suggestion is made that in following a specific subject more than one possibility be checked.

Comments on the value of this listing are welcome and are solicited by the Editor.

"THE KINETICS OF EXCHANGE ADSORPTION."—F. A. Ryan—May, 1951.
Professor E. R. Gilliland, *Massachusetts Institute of Technology*, 161 pp. Copies not available. Photostat 35¢ page. Microfilm $0.04 page. Work continuing.

"PHASE EQUILIBRIUM APPARATUS FOR PROPANE—GLYCERIDE SYSTEMS."—Robert C. Geitz—February, 1951.
Professor James Coull, *University of Pittsburgh*, 172 pp. 4 copies available.

"PREDICTION OF COMPOSITION CHANGES AND GRADIENTS IN SELECTIVE ADSORPTION COLUMNS."—R. J. Lombardo—June, 1951.
Professor Arthur Rose, *Pennsylvania State College*, 127 pp. 2 copies and abstract available. Work continuing.

"PREPARATION OF ADSORPTIVE CARBONS."—A. B. Metzner—March, 1951.
Professor W. K. Lewis, *Massachusetts Institute of Technology*, 231 pp. Copies not available. Photostat 35¢ page. Microfilm $0.04 page. Work continuing.

"USE OF SALT SOLUTIONS AND SOLID ADSORBENTS TO DEHYDRATE GASES AND ORGANIC LIQUIDS."—C. A. Stokes—May, 1951.
Professors T. K. Sherwood and H. P. Meissner, *Massachusetts Institute of Technology*, 275 pp. No copy available. Photostat 35¢ page. Microfilm $0.04 page. Work continuing.

CHEMICAL PROCESSES

"ACTIVATED ALUMINA AS A CATALYST FOR ANILINE CONDENSATION."—C. W. Roos—September, 1951.
Professor D. F. Chamberlain, *Washington University*, St. Louis, Mo., 164 pp. 2 copies available.

"AZO DYES FROM HETEROCYCLIC NITROGENOUS COMPOUNDS."—R. K. Charlesworth—June, 1951.
Professor R. Norris Shreve, *Purdue University*, 140 pp. 1 copy available. Negative photostat 30¢ page, positive 60¢ page. Microfilm $0.03 to $0.10 page. Work continuing.

"AZO DYES FROM 6-METHYL-2-NAPHTHOL."—A. A. Gunkler—January, 1951.
Professor R. Norris Shreve, *Purdue University*, 85 pp. 1 copy available. Negative photostat 30¢ page; positive photostat 60¢ page; microfilm $0.03 to $0.10 page. Work continuing.

"ENTRAINMENT STUDIES."—Clifford L. Carpenter—June, 1951.
Professor D. F. Othmer, *Polytechnic Institute of Brooklyn*, 90 pp. None available. Work continuing.

"THE LOW PRESSURE FORMING OF THERMOPLASTS."—Walter Brenner—June, 1951.
Professor D. F. Othmer, *Polytechnic Institute of Brooklyn*, 417 pages. None available. Work continuing.

"HIGH PRESSURE HYDROGENATION AND VACUUM RETORTING OF COLORADO OIL SHALE."—J. W. Pringle—May, 1951.
Professor Paul L. Barrick, *University of Colorado*, 59 pp. 1 copy available. Work continuing.

"PREPARATION OF VANADIUM METAL."—John R. Long—August, 1951.
Professor H. A. Wilhelm, *Iowa State College*, 50 pp. 2 copies available.

"PRODUCTION OF PURE SO_2—USE OF METAL OXIDES IN A FLUIDIZED POWDER SYSTEM."—T. K. Roy—May, 1951.
Professor E. R. Gilliland, *Massachusetts Institute of Technology*, 209 pp. None available. Photostat 35¢ page; microfilm $0.04 page. Work continuing.

"QUICK-CURING OF ORDINARY SUPERPHOSPHATE: DETERMINATION OF OPTIMUM OPERATING CONDITIONS ON A LABORATORY SCALE AND INITIAL PILOT PLANT WORK."—E. C. Kapusta—June, 1951.
Professor G. L. Bridger, *Iowa State*

College, 100 pp. 2 copies available. Work continuing.

"REDUCTION OF THE SULFUR CONTENT OF CERTAIN HIGH BOILING FRACTIONS."—James H. Gary—June, 1951.

PROFESSOR H. E. SCHWEYER, *University of Florida*, 66 pp. Publication in preparation. Abstract available.

"STEAM STRIPPING OF LARD."—Irving W. Wolf—June, 1951.

PROFESSOR J. H. RUSHTON, *Illinois Institute of Technology*, 81 pp. 1 copy available. Work continuing.

"A STUDY OF VAPOR PHASE CHLORINATION OF ETHYLBENZENE."—A. S. Jennings—September, 1951.

PROFESSOR D. F. CHAMBERLAIN, *Washington University*, St. Louis, Mo., 76 pp. 2 copies available.

"THE SYNTHESIS OF CRESOL."—Sven W. Englund—June, 1951.

PROFESSOR D. F. OTHMER, *Polytechnic Institute of Brooklyn*, 187 pp. 1 copy available.

"SYNTHESIS OF MELAMINE." H. V. Grubb—June, 1951.

PROFESSOR H. C. LEWIS, *Georgia Institute of Technology*, 72 pp. 2 copies available and abstract.

"WALLBOARD—BY DRY PROCESS WITHOUT THE USE OF RESINS."—L. G. Ricciardi—June, 1951.

PROFESSOR D. F. OTHMER, *Polytechnic Institute of Brooklyn*, 191 pp. None available. Work continuing.

COMBUSTION

"THE APPLICATION OF NEAR INFRARED WATER RADIATION TO THE MEASUREMENT OF FLAME TEMPERATURES BY A TWO-WAVELENGTH METHOD."—Hugh N. Powell—June, 1951.

PROFESSOR KURT WOHL, *University of Delaware*, 68 pp. 1 copy and abstract available. $0.04 per Ozalid page. Work continuing.

"COMBUSTION OF PULVERIZED FUEL."—Bimalendu Ghosh—June, 1951.

PROFESSOR A. A. ORNING, *Carnegie Institute of Technology*, 143 pp. 1 copy available. Work continuing.

"STABILITY AND STRUCTURE OF HIGH VELOCITY FLAMES."—Carl W. Weil—June, 1951.

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CORROSION

"PASSIVITY OF TITANIUM WITH SPECIAL REFERENCE TO HYDROCHLORIC ACID SOLUTIONS."—David Schlain—May, 1951.

PROFESSOR JOS. S. SMATKO, *University of Maryland*, 110 pp. 1 copy available. Library of Congress photostats available at its rates. Work continuing.

DESORPTION

"DESORPTION OF HYDROCARBONS FROM AN UNCONSOLIDATED SAND."—C. W. Oxford—June, 1951.

PROFESSOR R. L. HUNTINGTON, *University of Oklahoma*, 113 pp. 1 copy available and abstract. Photograph $1 page; microfilm $0.10 page.

DIFFUSION

"DIFFUSION IN LIQUID AND SOLID METALS."—Roger E. Eckert—October, 1951.

PROFESSOR H. G. DRICKAMER, *University of Illinois*, 135 pp. 2 copies and abstract available. Work continuing.

"DIFFUSION IN LIQUIDS NEAR THE CRITICAL POINT."—Walter L. Robb—October, 1951.

PROFESSOR H. G. DRICKAMER, *University of Illinois*, 97 pp. 2 copies and abstract available. Work continuing.

"DIFFUSION IN TWO-PHASE SYSTEMS."—Lu-Ho Tung—June, 1951.

PROFESSOR H. G. DRICKAMER, *University of Illinois*, 100 pp. 2 copies and abstract available. Work continuing.

"SPRAY FORMATION AND EVAPORATION."—James J. Donnelly—September, 1951.

PROFESSOR KURT WOHL, *University of Delaware*, 157 pp. 1 copy and abstract available. Ozalid copy $0.04 page.

"A STUDY OF THE DIFFUSION AND FLOW OF GASES THROUGH POROUS MEDIA."—F. J. Lavacot—September, 1951.

PROFESSOR W. P. ARMSTRONG, *Washington University*, St. Louis, Mo., 117 pp. 2 copies available. Work continuing.

DISTILLATION

"EFFECT OF HOLDUP AND REFLUX RATIO IN BATCH DISTILLATION."—Robert C. Johnson—January, 1951.

PROFESSOR ARTHUR ROSE, *Pennsylvania State College*, 194 pp. 2 copies and dittoed copies from Professor Rose. Work continuing.

"THE EFFECTS OF HOLDUP AND OTHER OPERATING VARIBLES IN BATCH DISTILLATION."—Harry A. Kahn—June, 1951.

PROFESSOR ARTHUR ROSE, *Pennsylvania State College*, 312 pp. 2 copies and dittoed copies available from Professor Rose. Work continuing.

"FACTORS AFFECTING PLATE EFFICIENCIES IN BUBBLE PLATE FRACTIONATORS."—Raymond W. Winkler—June, 1951.

PROFESSOR AARON ROSE, *Washington University*, St. Louis, Mo., 145 pp. 2 copies available. Work continuing.

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PROFESSOR F. C. VILBRANDT, *Virginia Polytechnic Institute*, 175 pp. Abstract prepared but not published. Work continuing.

ION EXCHANGE

"RATES OF ION EXCHANGE IN NON-AQUEOUS MEDIA." — F. S. Chance, Jr.—March, 1951.

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PHASE EQUILIBRIA

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"PHASE EQUILIBRIA IN TERNARY AND QUATERNARY SYSTEMS OF C$_5$ HYDROCARBONS WITH FURFURAL-WATER."—K. K. McMillin—May, 1951.

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"THE SOLUBILITY OF METHANE AND OF ETHANE IN WATER AT TEMPERATURES TO 340° F. AND PRESSURES TO 10,000 LBS./SQ.IN. ABSOLUTE."—O. L. Culberson—June, 1951.

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SOLUTIONS

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"LIGHT SCATTERING NEAR THE CRITICAL POINT."—L. G. Blosser—June, 1951.

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THERMODYNAMICS

"AN EXPANSION APPARATUS FOR THE DETERMINATION OF SOME THERMODYNAMIC PROPERTIES OF FLUIDS AT HIGH PRESSURES."—Richard J. Shields—June, 1951.

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UNCLASSIFIED

"THE CONCENTRATION OF THE STABLE ISOTOPE OF SULFUR OF MASS 34."—E. D. North—June, 1951.

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"ENERGY - NEW SURFACE RELATIONSHIP IN THE CRUSHING OF SOLIDS. V. IMPACT CRUSHING OF SINGLE PARTICLES OF CRYSTALLINE QUARTZ."—L. J. Heney, Jr.—August, 1951.

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"A STUDY OF THE FACTORS AFFECTING HOME HUMIDITY CONTROL AND THE VENTING OF GAS APPLIANCES."—Samuel C. Hite—January, 1951.

PROFESSOR J. L. BRAY, *Purdue University*, 200 pp. 1 copy available. Photostats, negative 30¢ page; positive 60¢ page; microfilm 3 to 10¢ page. Work continuing.

C. R. Wilke, left, winner of the Junior Award, and C. G. Kirkbride, Professional Progress Award recipient, exchange compliments after the presentation.

Session No. 1 opened with a note of welcome sounded by W. H. Barcus, chairman, Philadelphia - Wilmington section.

BALANCED PROGRAM FEATURES ATLANTIC CITY MEETING

A BALANCED meeting skillfully planned by the program committee, which featured outstanding and exhaustive technical programs with interesting and varied nontechnical subjects, featured the 44th Annual Meeting of the A.I.Ch.E. held at Atlantic City, Dec. 2-5, 1951.

Two of the three major addresses at the meeting, concerned problems with which our technical civilization must grapple if the full promise of scientific development is to be realized. The Professional Progress Award address by Chalmer G. Kirkbride, vice-president and director of Houdry Process Corp., concerned the effect of taxation on our technical progress. The full talk is printed in this issue of Chemical Engineering Progress (see page 44). At the Awards banquet, Hon. Thomas E. Murray, U. S. Atomic Energy Commission, spoke on the ethical aspects of our atom age in a well-received talk titled, "Some Limitations of Science." The complete address by Mr. Murray will appear in the February issue of "C.E.P." In the other major address, the Institute Lecture by Thomas Bradford Drew, covered the chemical engineering aspects of diffusion and our present state of knowledge of this important unit operation.

A total of 1564 went to Atlantic City for the meeting, which began Sunday with an afternoon discussion on "Whither Chemical Engineering Science." A panel of J. C. Elgin of Princeton University, K. H. Hachmuth of Phillips Petroleum Co., R. L. Pigford of University of Delaware, J. H. Rushton of Illinois Institute of Technology, and T. K. Sherwood of Massachusetts Institute of Technology, with G. G. Brown of University of Michigan as moderator, discussed modern trends in chemical engineering, with special emphasis on the mechanistic fundamentals underlying unit operations. The purpose was to explore developments of the past several years where chemical engineers have uncovered principles which make common bond with operations formerly

MEETING HIGHLIGHTS

- **Total Attendance 1564, Largest Annual Meeting Since 1949.**
- **Professional Progress Award to C. G. Kirkbride of Houdry Process Corp., W. H. Walker Award to R. H. Wilhelm of Princeton University; Junior Award to C. R. Wilke of University of California.**
- **David I. Saletan, University of Michigan, Won the Award for the Best Presentation of a Paper. Honorable Mention Went to H. D. Evans, Shell Development Co.**
- **Banquet Address by Honorable Thomas E. Murray, U. S. Atomic Energy Commission.**
- **Secretary Reports Membership Still Rising; now at 11,440.**

William I. Burt, A.I.Ch.E. President for 1952 and General Technical Program chairman talks with his line-up of speakers. They are Charles E. Dryden, Battelle Memorial Institute, Aaron Rose, Washington University, and A. E. Dukler, University of Delaware.

Karl W. Rausch, Jr., admires the certificate which declares that he was the 1951 Student Contest winner.

Best Presentation award went to David I. Saletan, University of Michigan.

"Whither Chemical Engineering Science?" It took Chairman G. G. Brown, left, his panel and numerous experts from the floor to decide that question.

thought to be separate.

In opening the discussion, the moderator, G. G. Brown, defined chemical engineering science "as the accumulated and accepted knowledge which has been systematized or formulated for use by the chemical engineer in the practice of his profession." The view to the future was opened by Professor Elgin who divided chemical processes into two zones —the chemical reaction zone and the separation zone. These were further individually subdivided in the chemical change zone of the simultaneous operations of mixing, physical solution and precipitation, chemical reaction, mass transfer, fluid motion, and heat transfer. These are governed by chemical thermodynamics, chemical kinetics, combined with kinetics of heat and mass transfer, the mechanics of fluid flow, fluidization, and mixing. "The separation zone," Professor Elgin said, "is divided into two classes—mechanical and phase change separation. All of the three possible phases, liquid, solid, and gas or vapor, can be treated with the same fundamental laws and all have the same basic principles and design theory."

R. D. Hoak, left, presided during the symposium on Industrial Waste Disposal, and C. C. DeWitt of Michigan State presented one of the papers.

It is around these broad principles that Professor Elgin thinks chemical engineering science will be systematized in the future. The second panel member, Dr. Hachmuth, on the other hand, listed the essential divisions of chemical engineering science as—mathematics, stoichiometry, thermodynamics, reaction kinetics, material transfer, and energy transfer. "An adequate knowledge of all these factors," he said, "is necessary for successful process design and operation."

Professor Pigford agreed essentially with Professor Elgin that many of the chemical engineering activities could be classified under the single heading of phase equilibrium and phase separation. He elaborated further on a point raised by Hachmuth that there were subjects which the Elgin classification did not include. He elaborated on one particular philosophy, namely, that chemical engineers should use whatever fields of science necessary to do their jobs. He warned against the handbook approach to engineering and said chemical engineering "inherited from the chemists the philosophy of experimentation, and no other branch of engineering indulged in experimentation to the extent the chemical engineers do." He stressed the fact that the whole field of applied science is open to the chemical engineer and that the physical chemists and physicists, by turning to new fields of endeavor, have left to the chemical engineer complete fields of experimentation in science which will not be developed properly unless chemical engineers do it. He ended by stating that ". . . in the future chemical engineers should try to develop their general understanding of scientific principles including chemistry, physics, physical chemistry, and mechanics to a degree greater than that which they have done so far."

T. B. Drew of Columbia University delivered the Third Institute Lecture. The subject was "Diffusion—What We Know and What We Don't."

Professor Rushton also warned against crystallization of the present form of chemical engineering through the use of unit operations, and stated that the path to the future is to recast our present notions of reaction rates, kinetics, and the so-called unit operations by using broader basic fields such as fluid mechanics, mass transfer, and energy transfer. Professor Rushton predicted that in ten years our major chemical engineering courses would include: first, the mechanics of fluid and energy transfer with extension to all rate mechanisms; second, the material and energy balances and rate coefficients; third, thermodynamics; fourth, reaction kinetics and catalysis; fifth, equipment for industrial operation;

Opening-night "Get-Together," with music and refreshments, jammed the largest ballroom.

Frank J. Smith chaired a General Technical session, and James I. Harper presented a paper on "The Arosorb Process."

The subject "Rapid Reading" was explored by Eugene Ehrlich, left, Department of English, Columbia University, and meeting chairman L. P. Scoville, center, demonstrates by way of his program. This stimulating session was rounded out by R. L. Atwood of Harvard who discussed "Effective Speaking."

Frank Curtis, left, led a sales discussion. The salesman he is listening to here is P. C. Keith, who told how to sell equipment.

sixth, process design; seventh, research. He said that he visualized the development of chemical engineering as an extension of mechanics, reaction kinetics, and thermodynamics to process integration. He called for a cessation of the tendency to petrify the science of our field, and asked that things be kept fluid.

Dean Sherwood began by quoting Einstein to the effect that "Scientists are those people who solve the problems which they can solve, and engineers are the people who solve the problems which have to be solved." His point was that decisions are made in engineering, construction, design, and management, with inadequate data. But in making such decisions, the highest form of engineering is practiced, Dr. Sherwood said. Any framework for systematizing chemical engineering knowledge, he claimed, is largely based on facts which we now know. Dr. Sherwood said that it might be helpful to consider chemical engineering as being divided into three areas: basic science, techniques of application, and finally the application itself. His particular philosophy called for continuing new developments and pushing back the frontiers of chemical engineering, and not to restrict our coverage of basic science to present known applications. He closed by saying that ". . . as the profession matures, let us guard jealously our traditional fundamental approach to new technological problems and not follow the older branches of engineering down the deadend road of empiricism."

"Chemical Engineering Fundamentals" were the topics of Robert D. Ingebo, H. D. Evans, and their chairman, Wayne C. Edmister.

Presided over by Alan Foust, left, in the afternoon session, and Donald Katz, next, in the morning session, the innovation of this symposium on "Heat Transfer" was the availability of preprints of the complete papers. Only a brief résumé of the papers was presented at the beginning of the meeting. The balance of the panel includes Joseph L. Schweppe, B. F. Harvey, John A. Beutler, E. P. Lynch, Charles F. Bonilla, I. R. Dunlap, Jr., and Irvin Glassman.

The discussion from the floor was varied, many different ideas being presented. Some speakers emphasized that the distinguishing characteristic of the chemical engineer was that he included chemistry, as well as physics and mathematics in his basic science. All in all, there was a definite indication that a trend toward simplification of chemical engineering classifications was in progress. The opinion was expressed that the unit operations should themselves be unitized or merged into groups according to common fundamental principles or methods of treatment. However, in

(*Continued on page 28*)

One future member found this pile of pillows to his liking. For most, meetings were paramount and anyway, the weather was cool.

"The Howells," glass-blowers, entertain the ladies.

SOUTH AMERICA'S ALKALI PLANT IN OPERATION

The Betania alkali plant, located 30 miles north of Bogota, Colombia, will be South America's first major alkali production facility when it goes into operation this year. Construction of the plant started in 1948.

Designed and constructed by The H. K. Ferguson Co., the plant will produce by the ammonia soda process 36,500 metric tons of soda ash, from which are produced 18,250 metric tons of dense ash, 9,125 tons of chemical caustic, 4,380 metric tons of bicarbonate of soda and 3,600 metric tons of light soda ash. Built for the Institute de Fomento Industrial, the Colombian governmental agency in charge of industrialization and the National Bank of Colombia, which controls salt properties, the plant cost approximately $15,000,000.

Principal raw materials for the plant are brine, which will be pumped five miles from the Zipaquira salt mines and limestone, which will be hauled from nearby deposits. Coal, another major raw material, is also readily available.

A.S.M.E. AWARDS THREE MEDALS

Three engineering honors were awarded at the 72nd annual meeting of the American Society of Mechanical Engineers, Chalfonte-Haddon Hall, Atlantic City, on Nov. 28.

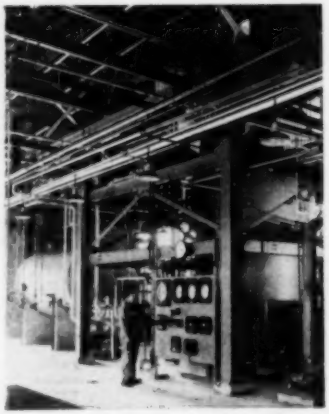
Recipients were William L. Batt, minister in charge of the Economic Cooperation Administration Mission to the United Kingdom, who received the Hoover Medal; Ervin G. Bailey, vice-president of the Babcock and Wilcox Co., of New York, awarded the John Fritz Medal, and Thomas Roy Jones, president of Daystrom, Inc., Elizabeth, N. J., winner of the Henry Laurence Gantt Medal.

The Hoover Medal for 1951 was awarded to Mr. Batt for "leadership in engineering, management and public responsibility, and his many distinguished services to his community and the nation." The medal is a joint award of the A.S.M.E., A.I.M.E., A.S.C.E., and A.I.E.E. It was established in 1930 to commemorate the civic and humanitarian achievements of Herbert Hoover, former President of the U. S., to whom the first award was made.

The John Fritz Medal was presented to Mr. Bailey for "outstanding engineering achievements in the field of combustion and distinguished service to his fellows in advancing the engineering profession." Mr. Bailey is founder and chairman of the board of the Bailey Meter Co., of Cleveland.

Mr. Jones was chosen winner of the Gantt Medal for "distinguished achievement in industrial management as a service to the community." The medal is a joint award annually of the A.S.M.E. and the American Management Association for achievement in industrial management service to the community.

NEW BAKER PLANT



Inorganic chemicals of high purity are manufactured in this new plant, part of a $3,000,000 expansion and modernization program at the J. T. Baker Chemical Co. works in Phillipsburg, N. J. Here, product purification, crystallization, drying and packaging are done under one roof. The crystallization tank, far left, feeds to the crystallizer, shown behind the instrument panel. Not shown in the picture are solution tanks where raw materials are dissolved and reacted before being filtered and fed to the crystallation feed tank. Production facilities include units to make ammonium sulfate, aluminum hydroxide, magnesium trisilicate, and penicillin.

PENNSALT TO ADD CHLORINE UNIT

Pennsylvania Salt Manufacturing Co. will add new facilities to its Calvert City (Ky.) works, including an electrolytic chlorine-caustic soda unit, at an estimated cost of $8,000,000.

Pennsalt completed in 1949 a hydrofluoric acid and sulfuric acid plant on its Tennessee River location near T.V.A.'s (Ky.) dam. These facilities were expanded in 1950, by a unit to produce end products from captive hydrofluoric acid and, now nearing completion, a 33 per cent increase in hydrofluoric acid capacity.

Addition of the new unit will combine at one works hydrofluoric acid, sulfuric acid, chlorine and caustic soda. The new unit will also include facilities to make anhydrous hydrochloric acid.

The plant will use the DeNora electrolytic mercury cell, developed in Italy, which produces caustic soda of rayon-grade purity at concentration up to 72%. Power will be supplied by T.V.A.

MICH. PLANT FOR HOOKER

A new $10,000,000 plant for the manufacture of chlorine and caustic soda at Montague, Michigan, was projected last month by R. L. Murray, president of Hooker Electrochemical Co., Niagara Falls. The new plant is expected to be in operation by the end of 1953, with a yearly production rate of approximately 100,000 tons of all products. Design of the plant will be in charge of the company's engineering department. Total plant area near the shore of White Lake is more than 400 acres, including a brine field.

Hooker TS-3A cell will be used to convert salt brine. Brine is to be piped from the company's own wells a short distance from the plant site. A brine field of approximately 200 acres has been set aside and test drilling has proved a salt supply of high purity and more than a million tons per acre.

Natural gas discovered during the exploratory drilling indicates a possibility of sufficient gas to meet fuel requirements. The gas field is being proved by Taggart Brothers Gas Co. of Big Rapids, Mich.

M.C.A. CONFERENCE ON AIR POLLUTION ABATEMENT

The Manufacturing Chemists' Association will hold an Air Pollution Abatement Conference at the Hotel Statler, New York, Feb. 25 and 26, 1952. Technical sessions and a forum on "A Rational Approach to Air Pollution" will be attended by representatives of industries concerned with pollution.

(*More News on page 23*)

Dynamic Separation saves Money

INFILCO
* BETTER WATER CONDITIONING * AND WASTE TREATMENT SINCE 1914

OFFERED ONLY BY THE

Accelator®

IN ECONOMICAL WATER TREATMENT, an Accelator occupies but a fraction of the space of an "old-style" treatment plant because it is a single unit . . . because it eliminates the previous multiple steps of mixing, sedimentation and coagulation. The unique dynamic separation principle of operation

(continue to next page)

(from preceding page)

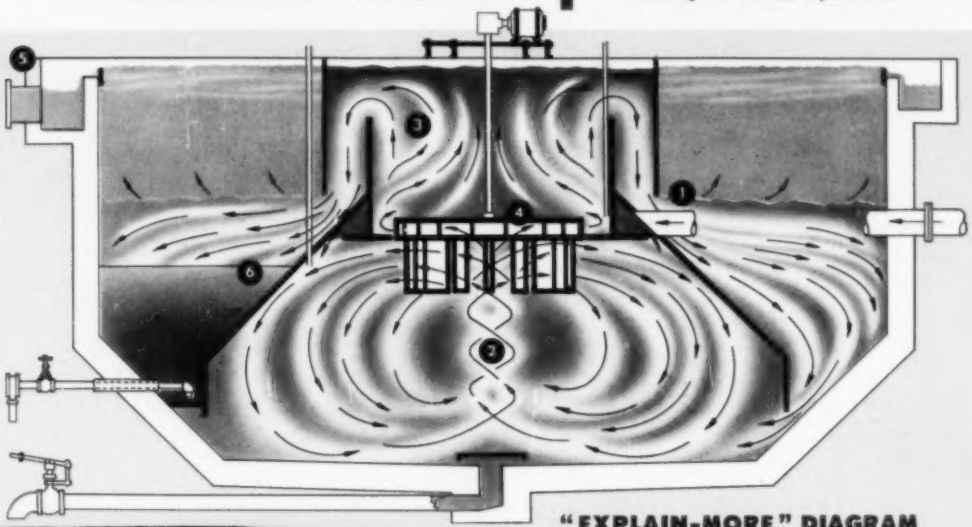
INFILCO
* BETTER WATER CONDITIONING AND WASTE TREATMENT SINCE 1934 *

permits the treated water to separate from the top of a downward-moving pool of uniformly sized slurry in contrast to having the treated water filter upward through a suspension of sludge of gradually decreasing particle sizes.

INFILCO INC. ★ *Tucson, Arizona*

Outstanding advantages—based on more than two thousand Accelator efficiency-of-operation reports:

- ★ Faster separation of solids from treated water
- ★ Low-velocity movement of tremendous quantities prevents floc break-up
- ★ Rapid mixing of incoming water and chemically impregnated slurry
- ★ Small or large flows have complete contact with slurry
- ★ Thickened sludge is automatically drawn off
- ★ Settling-out of solids is prevented

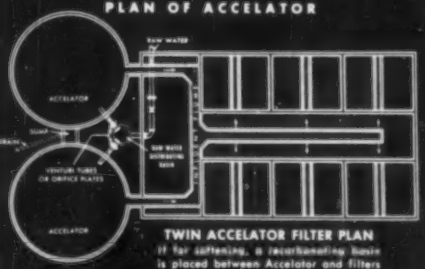


"EXPLAIN-MORE" DIAGRAM

the Accelator basin contains:

1. A raw water inlet and distributing duct
2. A primary mixing and reaction zone
3. Two concentric draft tubes which form the secondary mixing and reaction zone
4. A rotor-impeller for mixing and pumping, driven by a motorized reducer
5. An effluent launder system
6. Concentrators to accumulate and remove excess slurry

PLAN OF ACCELATOR



TWIN ACCELATOR FILTER PLAN
If for softening, a recarbonating basin is placed between Accelator and filters

TYPICAL ACCELATOR LAYOUT

SUGGESTED ACCELATOR APPLICATIONS / POSSIBLE TREATMENT REQUIREMENTS → / WATER END-USE	SOFTENING	CLARIFICATION	STABILIZATION	ALKALINITY REDUCTION	ORGANIC MATTER REMOVAL	TASTE AND ODOR REMOVAL	COLOR REMOVAL	IRON REMOVAL	SILICA REDUCTION	NEUTRALIZATION
MUNICIPAL	X	X		X	X	X	X	X		
PULP	X	X		X	X		X	X		
PAPER	X	X		X	X		X	X		
BEVERAGES		X		X	X	X	X	X		
COOLANT	X	X	X	X	X			X		
BOILER FEED	X	X		X	X		X	X	X	
RAILROADS	X	X					X			
TEXTILE	X	X			X		X	X		
CANNERIES		X		X	X	X		X		
BREWERIES		X		X	X	X	X	X		
OIL FIELD FLOODING		X	X		X		X	X		
BRINE DISPOSAL		X	X		X		X	X		
INDUSTRIAL WASTES DISPOSAL AND REFUSE		X	X		X		X			X

NEWS

(*Continued from page 20*)

L. I. DOAN ADVOCATES CORPORATE ECONOMY

Business should take the lead in practicing rigid economy and thereby earn the right to demand equal economy on the part of government, Leland I. Doan, president of The Dow Chemical Company, told a group of security analysts last month at Providence, R. I.

Commenting that it is easy to succumb to a philosophy of spending income dollars rather than hand them over in taxes, Doan said too little has been said about the "suicidal effect that the practice of such thinking would have on our total economy."

"Taxes," Doan declared, "must come from national production. If we who are responsible for production waste our dollars we are in a poor position to demand more judicious handling of our tax dollar by government."

Doan said his company paid $68 million in federal taxes last year and estimated it would pay more than $90 million next year. "This is pin money in the federal budget," he said, "but a shocking amount of money to be diverted from stockholders . . ."

"But we won't evade taxes by spending the money first," he declared. "Wasteful spending by corporations will only result in decreased tax collections, eventually to the point where further tax increases will be the only alternative."

ENGINEERING STUDENTS INCREASE IN CANADA

First-year registration of engineering students at Canadian universities in 1951 was up more than 10 per cent over 1950. This was the finding in a recent survey made by The Engineering Institute of Canada. Though the total enrollment of engineering students is down in 1951 from 8329 in 1950 to 7509, the trend has been reversed and the number of first-year registrations is 2105 compared to 1874 in 1950. On the basis of non-veteran enrollment in first year the figures are 2086 for 1951 and 1831 for 1950, giving a net increase this year of 255 or 14 per cent over the 1950 figure.

The number of prospective 1952 graduates is down from 1951. The prospects for employment of young graduate engineers next spring should be good. The shortage is not likely to be eliminated for quite a number of years unless the present level of engineering employment drops appreciably in the meantime according to the survey findings.

The report goes on to state that considering that Canada has been absorbing engineering graduates at a rate of more than 3000 a year for the past four years, the fact that fewer than 1500 per year are likely to be available during the next four years will have an effect on the economic use of engineers.

THE ATOM GOES ON TOUR

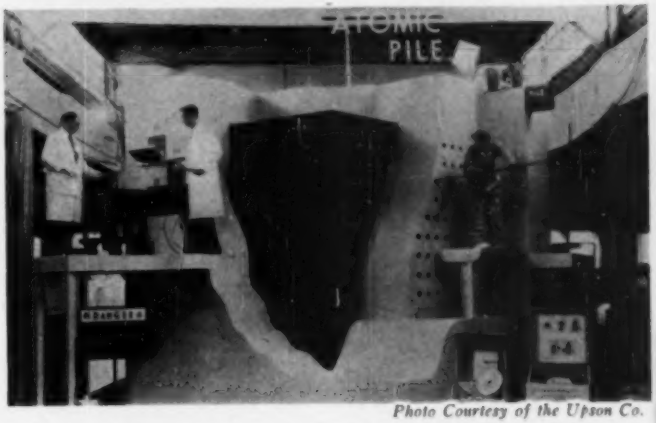


Photo Courtesy of the Upson Co.

Above is a mock-up of an atomic pile which is part of an exhibit on atomic energy now touring the nation. Sponsored by the American Museum of Atomic Energy, at Oak Ridge, Tenn., and the National University Extension Association, the trailer-housed unit will travel from coast to coast between now and next June when it returns to Oak Ridge.

Other exhibits include a van de Graff generator and a Wilson cloud chamber.

FLAME-SPRAYING GUN

Shown above is an operator spraying a mild steel tank with polyethylene plastic to protect it against corrosive chemicals. A Linde flame-spraying gun, specially developed for the purpose is used. The polyethylene particles are carried into the gun by a stream of compressed air, melted and sprayed by a high heat oxyacetylene flame. Various thickness of plastic can be built on the steel. "C.E.P." Data Service No. 22 in December described available literature on the technique.

COMPRESSED GAS ASSOC. TO MEET

The Compressed Gas Association, Inc., will hold its 39th annual meeting at the Waldorf-Astoria, New York, Jan. 21 and 22, 1952.

Technical sessions will be held on Monday afternoon, and Tuesday morning. Committee meetings will be held Monday morning.

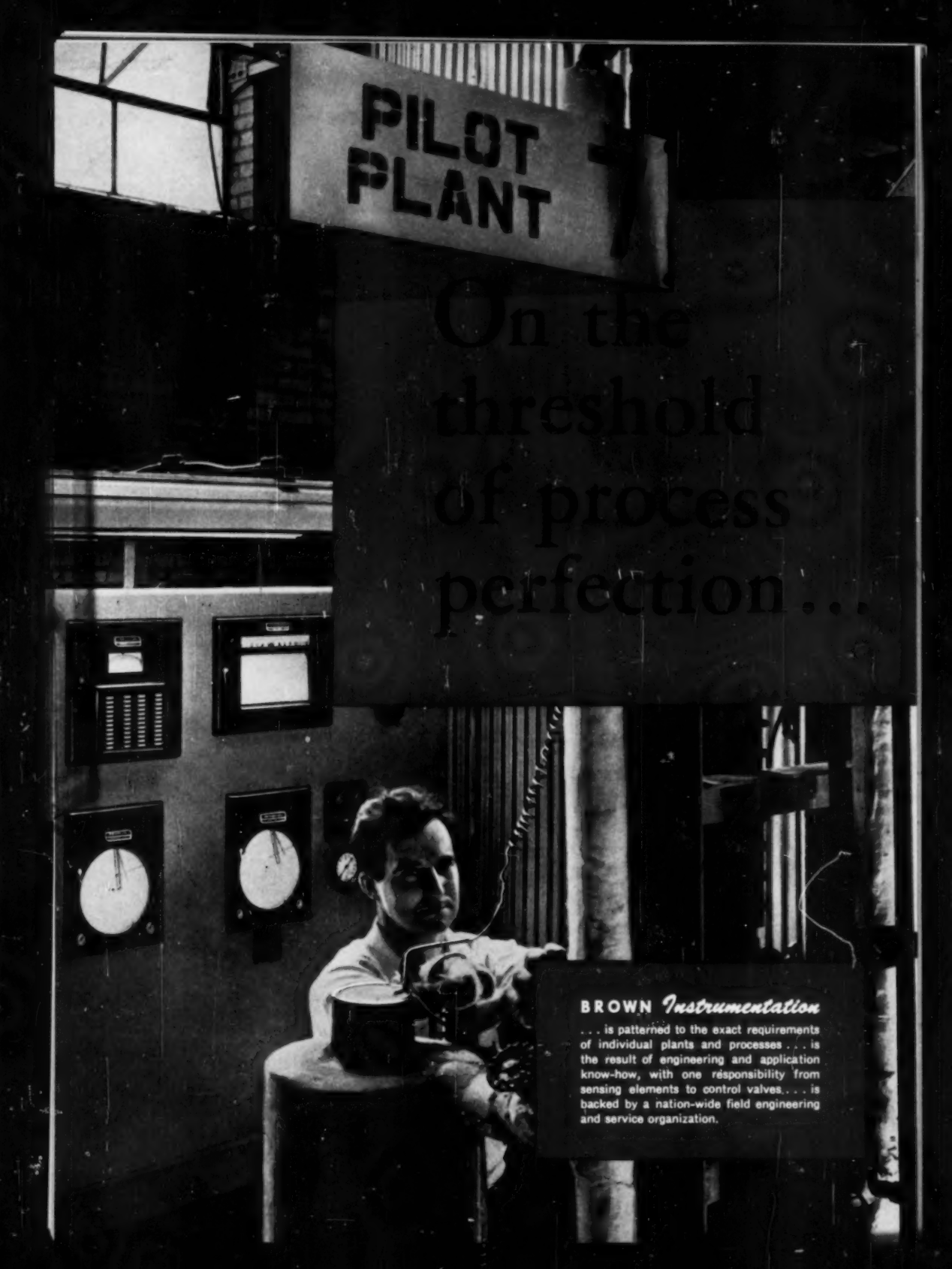
MONSANTO MOVE MAPPED

Monsanto Chemical Co. has taken options on several large tracts of land in St. Louis County, planning to establish its general offices there within the next few years. An announcement to this effect was made by Charles Allen Thomas, Monsanto president, who disclosed that expansion plans call for the construction of new headquarters on Lindbergh Road, south of Olive Street Road, in Creve Coeur. No manufacturing operations are involved.

The company's main offices have been located on South Second Street since the late John F. Queeny founded Monsanto in 1901. Currently, the general offices are located at 1700 South Second Street.

"We are anxious to complete plans for the erection of a building which will be the general headquarters for Monsanto's world-wide organization," Dr. Thomas added, "and we also are anxious to play a major role in the expansion and modernization of the Greater St. Louis area."

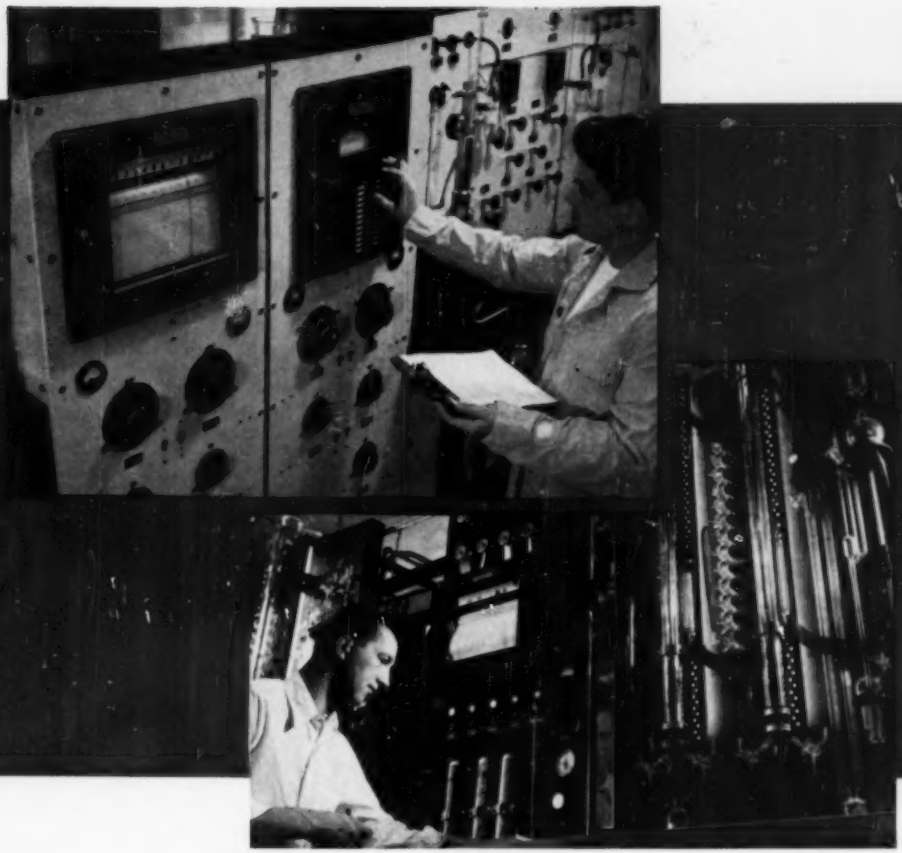
(*More News on page 26*)



On the threshold of process perfection . . .

BROWN *Instrumentation*

. . . is patterned to the exact requirements of individual plants and processes . . . is the result of engineering and application know-how, with one responsibility from sensing elements to control valves. . . . is backed by a nation-wide field engineering and service organization.



PROVING processes in the pilot plant stage can save untold millions of dollars in "on-stream" operations. But bridging the gap between fluid ounces per hour in the laboratory and hundreds or thousands of barrels per hour in the plant takes considerable doing.

Thorough instrumentation in the pilot plant provides . . . (1) *a saving in scientific man-hours,* through the centralization of critical data which eliminates the hand logging of hundreds or even thousands of points . . . (2) *easy and rapid interpretation of data,* through automatic coordination and recording in chart form . . . and (3) *process simplification,* through a complete understanding of control problems well in advance of full-scale operations.

Add to these advantages the fact that, with instruments, pilot studies are accomplished in much less time . . . for instruments *accelerate* research. Investigate the wide application possibilities of Brown Instrumentation. Our local engineering representative is qualified to discuss your requirements . . . and he is as near as your phone.

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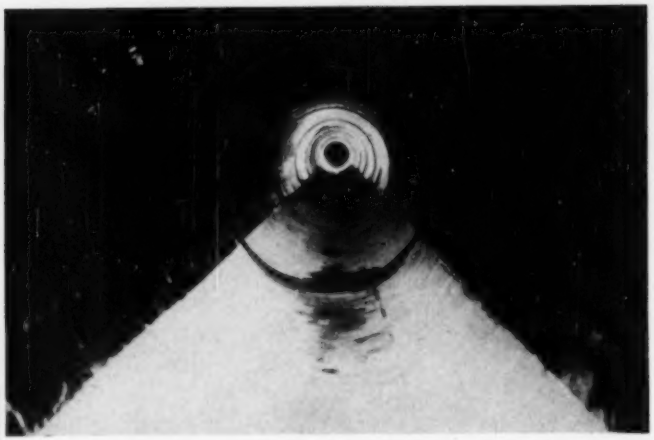
BROWN INSTRUMENTS
First in Controls

● *Important Reference Data*

WRITE FOR A COPY OF 84-PAGE BULLETIN NO. 15-14, "INSTRUMENTS ACCELERATE RESEARCH"... AND NEW BROCHURE, "TOMORROW IS TODAY."

VINYL PLASTIC-LINED SEWER PIPE



A section of the 48-in. I. D. reinforced concrete pipe, part of the 35,000 lineal feet Orange County Joint Outfall Sewer in California, all of which is lined inside three quarters of the way around with a plastic sheeting developed and manufactured by Amercoat Corp., South Gate, Calif.

The sheeting is made from Geon polyvinyl chloride resins, produced by B. F. Goodrich Chemical Co., Cleveland, Ohio, together with inert pigments and plasticizers and protects the concrete pipe against disintegration created by gases which arise from the sewage.

A.E.C. FELLOWSHIPS ANNOUNCED

Names of 343 holders of A.E.C.-sponsored fellowships were announced last month by the Oak Ridge Institute of Nuclear Studies. Five were in chemical engineering.

The Institute is administering the fellowship program for the Atomic Energy Commission for the 1951-52 school year.

Russell S. Poor, chairman of the Institute's university relations division, said that fellowships had been awarded for study at 70 American universities and research institutions and seven others located abroad.

The fellowships are for research and study on both the predoctoral and postdoctoral level, Dr. Poor said, with 300 predoctoral and 43 postdoctoral fellows. Of the predoctoral fellows, 223 are in the physical sciences and 77 are in the biological sciences. On the postdoctoral level, 21 are in the physical sciences, 17 in the biological sciences, and 5 in the medical sciences. The fellowship programs in chemical engineering will be carried out at Columbia University, University of Michigan, University of Minnesota, and Yale.

"The A.E.C.-sponsored fellowship program is playing a vital role in giving many of our promising young scientists the opportunity to continue their research and study," Dr. Poor said. "We do not have to go into the future to see a need for more scientists—the need is here now," he continued.

BERYLLIUM ANTIDOTE ANNOUNCED

A successful antidote for beryllium poisoning was announced recently by Jack Schubert of the Argonne National Laboratory. Aurin Tricarboxylic Acid has been found to be a nearly perfect antidote for otherwise fatal doses of beryllium compounds in animal experiments carried out by Dr. Schubert, Marcia R. White, Asher J. Finkel, and Arthur Lindenbaum of the Argonne Laboratory. ATA also gives protection when administered to animals before exposure to beryllium, the Argonne chemist said.

The metal beryllium, formerly used in fluorescent lamps and now employed as a source of radioactivity in the atomic energy program, has only recently been recognized as the cause of an insidious, slowly developing disease, Dr. Schubert told the Chicago Section of the American Chemical Society.

"Poisoning results from the presence of small amounts of beryllium metal or beryllium compounds in the body," Dr. Schubert explained. "Inhaled beryllium induces widespread damage in the lungs." No successful cure for the disease was known although temporary improvement in many patients had been obtained by the use of ACTH.

NEWS

(*Continued from page 23*)

SOIL STABILIZER A RECENT DEVELOPMENT

A process which may enable waste sulfite liquor to be used as a soil-stabilization agent for secondary roads has been developed by B. K. Hough and J. C. Smith, of Cornell University, according to a recent announcement of the Army Engineer Corps.

Waste sulfite liquor has been used for years as a dust palliative and for temporary stabilization of secondary roads and highway shoulders, but its value has been limited by its water solubility. Now the chrome-lignin process, developed under Army Engineer Corps sponsorship, shows promise of making sulfite liquor effective as a soil solidification agent.

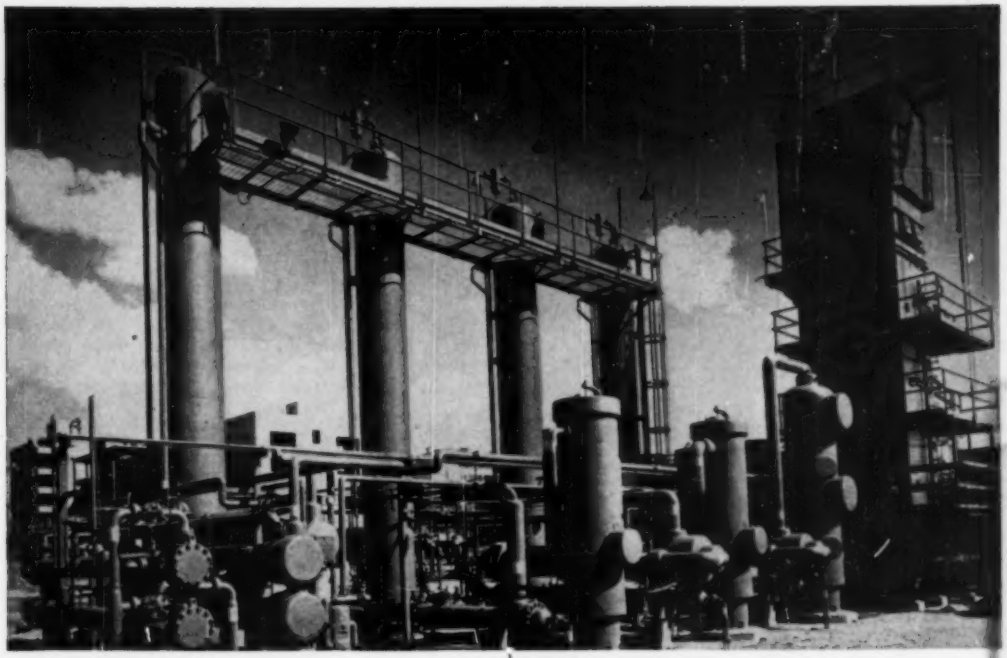
The process, as developed by the two Cornell men, is based on the reaction of sulfite liquor and sodium or potassium bichromate to form a water-insoluble gel. The addition of 3 to 10 per cent of concentrated sulfite waste and smaller quantities of bichromate imparts cohesive strength to soils, and makes them almost impervious to water. The additive is effective with a wide variety of soils, ranging from beach sands to heavy clays, and is not adversely affected by organic contamination in the soil.

EXPOSITION LARGEST EVER

The recent 23rd Exposition of Chemical Industries which was held in Grand Central Palace, New York, during the week of Nov. 26 to Dec. 1, proved to be the largest in the 36-year history of the show. According to the management, 457 exhibits were shown on the four floors of the Palace and close to 47,000 visitors were registered during the week.

Much of the new equipment and materials at the show was summarized by "C.E.P." in the November, 1951, issue and provision made there, via the Data Service, for our readers to obtain any of the literature for the new equipment.

Two events of importance to chemical engineering took place during the week—one, the Award of the 19th Annual Chemical Achievement Award to the Phillips Petroleum Co. for its successful development of high abrasion carbon blacks, and its major contributions to the development of a cold rubber process. This was noted in "C.E.P." in our November issue on page 23. The other was the introduction to the chemical engineering profession, of the book, "Tower Packings and Packed Tower Design," authored by Max Leva, a member of A.I.Ch.E. and chemical engineering consultant. It was published by the U. S. Stoneware Co.



HYDROGEN... pure and low cost for Lever Brothers Company at Los Angeles

FOR THEIR NEW Los Angeles plant, Lever has again installed a Girdler HYGIRTOL* plant to assure a dependable source of high-purity hydrogen for hydrogenation of vegetable oils used in Lever products. This plant, shown above, is the second Girdler hydrogen plant purchased by Lever Brothers Co.

Hydrogen purity with this process generally exceeds 99.8%. Instruments control the plant, which is practically automatic. Just one man is needed to supervise operation and to maintain hydrogen production at the desired rate.

Process material costs, as well as labor costs, are low. HYGIRTOL plants use natural gas, propane or butane for process materials. These hydrocarbons are reasonable in cost, are readily available and easy to handle.

HYGIRTOL plants are built outdoors to save the cost of a building.

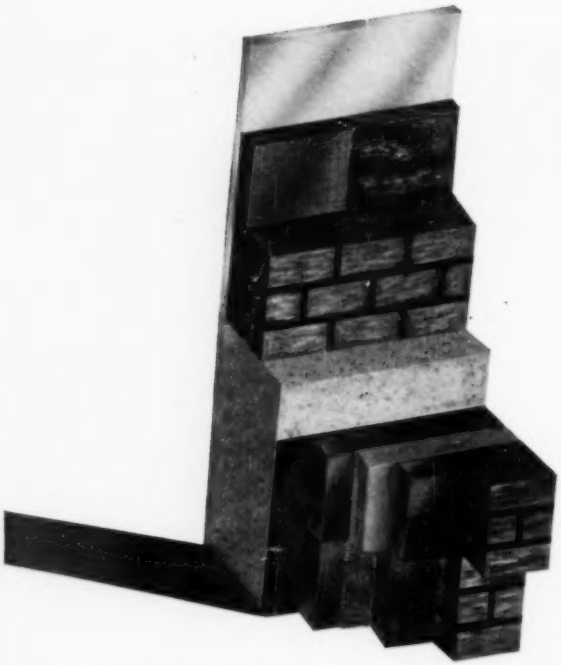
For planning and construction of *your* gas processing facilities, call on Girdler. You can do so with confidence. The Girdler Corporation, Gas Processes Division, Louisville 1, Kentucky.

Write for bulletin describing our services. The Girdler Corporation designs and builds plants for the production, purification, or utilization of chemical process gases; the purification of liquid or gaseous hydrocarbons; the manufacture of organic compounds.

Entrance to Lever Brothers Company new Los Angeles plant reflects modern design of all facilities and equipment. This plant will supply a variety of soap and shortening products to Western market areas.

* Hygirtol is a trade mark of The Girdler Corporation

THE GIRDLER CORPORATION
Gas Processes Division



in CORROSION-PROOF LININGS . . . there is no substitute for ATLAS experience

Portrayed above are a number of ATLAS lining constructions for use on steel or concrete. Each has definite applications where it will give you the best service obtainable for your operating conditions.

ATLAS engineers have always recognized that there is no one lining material or construction best for all applications. Accordingly, for sixty years they have accumulated intensive laboratory and practical field data pertaining to most known corrosives. Over this period, they have developed materials which individually or in combined constructions offer the best long-term resistance.

Knowing the corrosives involved, processing temperatures and other conditions, the ATLAS Technical Service will recommend specific materials and constructions for your application. They will tell you as plain facts what ATLAS materials *will* and *will not* do.

INFORMATIVE DATA on ATLAS *products will gladly be sent to you.*

Corrosion-proof LININGS . . . *Bulletin 4-2*
Corrosion-proof CEMENTS . . . *Bulletin 5-2*
Corrosion-proof COATINGS . . . *Bulletin 7-2*

ATLAS PRODUCTS STAND
. . . between your process and corrosion

ATLAS MINERAL PRODUCTS COMPANY
MERTZTOWN PENNSYLVANIA
HOUSTON 1, TEXAS

Corrosion-proof: Cements—Coatings—Vessel Linings

ATLANTIC CITY

(*Continued from page 19*)

Donald H. Buchanan and his listeners hear his "Applications of Integral Distillation Calculation Method."

general, it seemed the consensus was that no particular method of systematizing chemical engineering knowledge could or should be adopted by chemical engineers.

At the business meeting on Monday morning, various reports of committees

E. W. Comings, left, headed Technical Session No. 12, and James G. Knudsen of Oregon State read his paper "Pressure Drop in Annuli Containing Transverse Fin Tubes."

were heard including the Tellers' report. News of the election of the new officers was made in the December issue of "C.E.P."

The annual report of Council was read by the Secretary and is printed elsewhere in this issue.

The third Institute Lecture, "Diffusion—What We Know and What We Don't," by Thomas Bradford Drew, head of the department of chemical engineering at Columbia University, will appear as the second volume of the Chemical Engineering Progress Monograph Series some time this year.

Entertainment at Atlantic City consisted of a casino night in which guests were given bogus money for use at various games of chance. An informal open house and entertainment on Sunday evening, and a cocktail party and

(*Continued on page 32*)

NOT A COATING . . .

NOT AN ENAMEL . . .

NOT A GLAZE . . .

Solid Porcelain

NON-POROUS THROUGH-AND-THROUGH

The dependability and long life of the Lapp Valve is due to its sound design, and to the fact that it is made of *porcelain* . . . body, plug and packing rings. Not a coating or enamel, porcelain is a dense, homogeneous, thoroughly-vitrified ceramic, *non-porous,* through-and-through acid resisting. Not even is the corrosion-resistance of this material due to a glaze. In fact the "working parts" have no glaze. The smooth operation and pressure-tight seal characteristic of Lapp Valves result from precision-tolerance machining . . . grinding and lapping of solid porcelain to a mirror-like smoothness.

Valves and other equipment of Lapp Chemical Porcelain may be the answer to your corrosion problems. Write for literature. Lapp Insulator Company, Inc., Process Equipment Division, 485 Maple St., LeRoy, N.Y.

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PROCESS EQUIPMENT

CHEMICAL PORCELAIN VALVES • PIPE • RASCHIG RINGS

PULSAFEEDER CHEMICAL PROPORTIONING PUMPS

MARGINAL NOTES

News of Books of Interest to Chemical Engineers

The Sky Around Us

"200 Miles Up." J. Gordon Vaeth. The Ronald Press Co., New York (1951). 207 + xiii pp. $4.50.

Reviewed by R. B. Canright, Research Engineer, Jet Propulsion Lab., California Institute of Technology, Pasadena, Calif.

EXCEPT for occasional snatches of fragmentary information gleaned from newspaper headlines, knowledge of the progress of the recently augmented field of upper atmosphere research is not generally possessed by the practicing engineer. Mr. Vaeth's book gives an over-all picture of the achievements in this field, with emphasis placed on the instruments and vehicles which have made flights to above 200 miles possible. The book is essentially nontechnical in treatment, but an outlook conditioned by training in physics or engineering is desirable for the reader.

The first chapters deal with the structure of the atmosphere as presently conceived, and endeavor to show the layman why research in this field is important. Then come chapters dealing with primary measuring instruments and secondary instruments, for observing and recording the information obtained from the flights of the vehicles. There is also included a chapter giving a qualitative treatment of the principles of rocket flight. The remaining chapters deal with the descriptions, and methods of operation, of the vehicles most often used in these studies. Such vehicles include the plastic balloons of "Project Skyhook," and the V-2, Aerobee, and Viking rockets.

The book is amply illustrated with sketches and photographs—in fact, the series of photographs of the vicinity of White Sands as taken from rockets at various altitudes up to 70 miles is the best this reviewer has seen collected. The author is also to be complimented on the end plates chosen, which show graphically the general structure of the atmosphere and man's penetrations through it. However, the author sometimes emphasizes the upper atmosphere program at the expense of the rest of the rocket research program in this country, which is mainly classified for security reasons.

An example of this trend is given in Chapter 6, where he states that the White Sands Proving Ground, which is exactly what its name implies, is ". . . . now recognized as an upper atmosphere rocket research center . . . ." Since progress in the field of upper atmosphere research has been relatively rapid, the records and data quoted will rapidly become obsolete, if they have not already done so, such as the recent record-breaking flight of the Viking to 135 miles.

Nevertheless, "200 Miles Up" can be recommended to those who are interested either in rockets, or in the upper atmosphere itself, or in the interplay of the advancements of technology with the advances in pure science.

Organic Cookbook, Opus 31

Organic Syntheses, Vol. 31. R. S. Schreiber, Editor in Chief. John Wiley & Sons, Inc., New York. (1951) vi + 122 pp. $2.75.

Reviewed by Kenneth A. Kobe, Professor, Chemical Engineering, University of Texas, Austin, Tex.

SINCE 1921 a volume of Organic Syntheses has appeared annually giving a number of tried and true syntheses for various organic compounds. The procedures given are concise and explicit. They have been checked in different laboratories to insure the reproducibility of the results. The compounds presented are usually research chemicals rather than industrial chemicals which can be purchased.

The present volume adds 41 compounds to those presented in previous volumes. Organic Syntheses is a must for the organic research laboratory.

Books Received

German Books on Chemical and Cognate Subjects, published 1939-1950. Second revised and extended edition. A. E. Cummins and S. Vince. Lange, Maxwell & Springer Ltd., London, W.C. 2. (1951.) 102 pp. (Publication not for sale. Supplied free of charge on request to scientific and industrial libraries as well as to interested individuals.)

Instrumentation for the Process Industries. Proceedings of the Fifth Annual Symposium on Instrumentation for the Process Industries. Conducted by Agricultural and Mechanical College of Texas, College Station, Tex. Instruments Publishing Co., 912 Ridge Ave., Pittsburgh 12, Pa. (1950) 64 pp. $2.50 postpaid.

Solid-Solid Behavior

Phase Transformations in Solids. R. Smoluchowski, J. E. Mayer, W. A. Weyl, Editorial Committee. John Wiley & Sons, Inc., New York. (1951) 660 pp. $9.50.

Reviewed by M. J. Sinnott, Assoc. Professor, Chemical Engineering, University of Michigan, Ann Arbor, Mich.

THIS book is the outgrowth of the work of the National Research Council Committee on Solids whose principal object was to examine the basic problems of the solid state and to encourage progress in this field. The book deals generally with the many aspects of phase changes as they are encountered by diverse groups such as physicists, chemists, metallurgists, crystallographers, ceramicists, and engineers.

The text consists of some 17 papers by individual authors who are experts on the topics they present. Each paper can stand alone; the only thread of connection is that some particular aspect of phase behavior is under discussion. An attempt was made to present first theoretical papers, then papers on nonmetals and finally papers on metals. The general caliber of the papers is high but not all topics receive the same degree or intensity of treatment. It is apparent that metallic solids have received the major emphasis. The paper on Precipitation from Solid Solutions of Metals, for example, contains some 830 references and is an excellent summary of the present and past status of this field. Papers dealing with materials such as silicates, halides, and ferroelectrics, on the other hand, while interesting, are not as comprehensive.

It appears that this book would be of more interest to those working in the metallic solid field and would be of only general interest to those working in nonmetallics. It would not be classified as a reference book but is more of a survey of the existing data and theories of certain phases of solid behavior. It would probably not be of too much interest to a practicing engineer except to bring him up to date on some of the newer developments in solid-state behavior. It would be of great interest to the research and development personnel in that in the one volume the entire field of solid-phase behavior is expertly presented and well documented.

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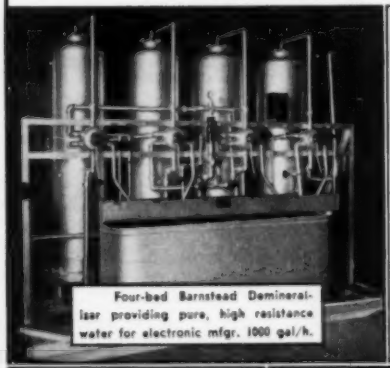

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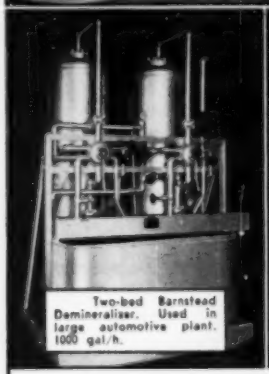

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ATLANTIC CITY

(*Continued from page 28*)

Awards banquet on Tuesday.

It was at the Awards banquet that Commissioner Murray delivered his address on "Some Limitations of Science" in which he asked the chemical engineers to consider the implications of atomic warfare. During his talk Commissioner Murray said that he wanted the scientists to ". . . look beyond our stockpile of weapons, beyond atomic

A gaming, or "Casino Night." Time to relax from "Whither Chemical Engineering Science."

submarines, atomic aircraft, beyond chemical discoveries, even beyond science. All in all it is recognized that science is a tool. It is a means not an end or a false god." He claimed that "for scientists to use science well, they must know something of its potentialities and something of its limitations." As far as limitations are concerned, the atomic energy commissioner said, "while science can give man mastery over matter, it can fail to give man control over himself. That while he could experiment with tools, machines, and chemicals, he could not experiment with souls, and lives, and honor of men. Science never reaches ultimates and even though it may smash atoms it never reaches the ultimate particle which is this side of nothing." The commissioner pointed out that while science is a closed system, religion and philosophy are open systems. In discussing the crisis today, he maintained that it came solely from the "greed of men and their will to power regardless of conscience."

In his concluding sentences Mr. Murray followed by stating ". . . this is not a random world . . . . because all things that are made by God, man's attention should never be so focused on science, as to neglect religion and philosophy which can direct our lives according to right, reason, and charity. If men will not clothe their framework of science with the warm garments of true humanism, they will end up by making machines their god and mathematics their only dogma."

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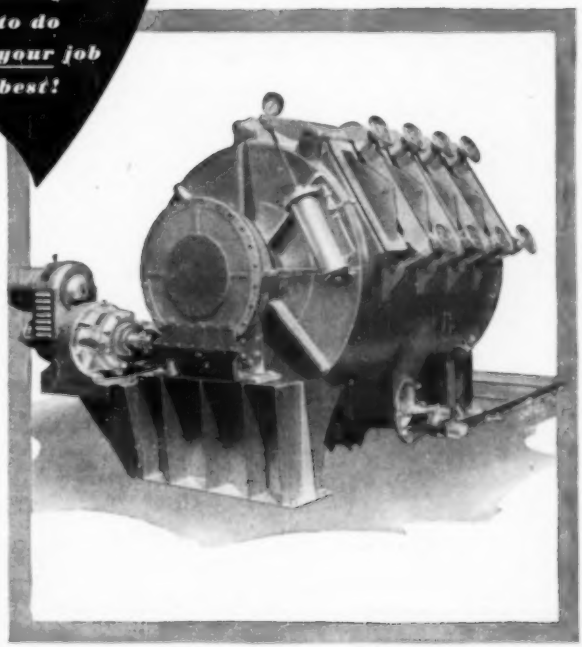

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before February 15, 1952, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

Abrams, Richard S., *Williamsville, N. Y.*
Allen, James B., *Houston, Tex.*
Amundson, Neil R., *Minneapolis, Minn.*
Anderson, Nils K., *Cushing, Okla.*
Atwater, Robert M., *Snyder, N. Y.*
Carlson, Walter M., *West Chester, Pa.*
Cavanaugh, Robert M., *Wilmington, Del.*
Chetrick, M. H., *Grand Forks, N. D.*
Corn, Lawrence H., *Pittsburgh, Pa.*
Daley, Henry G., *Naples, Italy*
Dameus, John G., *Charleston, W. Va.*
Dech, Carl W., *Wilmington, Del.*
Dewey, Bradley, Jr., *Concord, Mass.*
Dodds, Wayne S., *Chicago, Ill.*
Flitcraft, R. K., *Monsanto, Ill.*
Garrels, John C., Jr., *Springfield, Mass.*
Gillmor, Robert E., *Rochester, N. Y.*
Glenn, William M., *Louisville, Ky.*
Gray, Earl H., *Bartlesville, Okla.*
Holt, Ernest K., *New York, N. Y.*
Jacks, Robert L., *Baton Rouge, La.*
Joseph, Charles W., Jr., *Decatur, Ala.*
Land, Hugh C., *Drexel Hill, Pa.*
Lee, Richard D., *San Pablo, Calif.*
Leuenberger, Hans, *Niagara Falls, N. Y.*
Lewis, John G., *Ann Arbor, Mich.*
McAfee, Jerry, *Pittsburgh, Pa.*
McNally, Robert J., *Wilmington, Del.*
Merman, Robert G., *Philadelphia, Pa.*
Mitchell, Roy C., *Terre Haute, Ind.*
Moore, John A., *Texas City, Tex.*
Newman, Henry F., *Chicago, Ill.*
Roe, Warren A., Jr., *Pittsburgh, Pa.*
Siegel, Milton R., *Wilson Dam, Ala.*
Stevens, Robert J., *Hawkesbury (Ont.), Canada*
Stockdale, Walter G., *Oak Ridge, Tenn.*
Stratman, F. H., *Louisville, Ky.*
Tennant, Frank M., *Midland, Mich.*
Torrans, David J., *Parlin, N. J.*
Wallman, Harold, *Stamford, Conn.*
White, Philip C., *Texas City, Tex.*
Young, James H., *Wilmington, Del.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

Boch, Thomas R., *Nitro, W. Va.*
Hunt, Walter J., *Richmond, Va.*
Sweny, John W., *El Cerrito, Calif.*

APPLICANTS FOR JUNIOR MEMBERSHIP

Ainsworth, George E., *Auburn, Me.*
Alancraig, Charles R., *Salinas, Calif.*
Allinger, F. S., Jr., *Balboa Island, Calif.*
Anderson, Thomas O., *St. Louis, Mo.*
Ashwill, Richard E., *Wilmington, Del.*
Barnett, J. C., *Monsanto, Tenn.*
Basso, John A., *Negaunee, Mich.*
Bazard, Walter S., Jr., *Houston, Tex.*
Becker, Marvin, *Springfield, Mass.*
Bell, Evan W., *Easton, Pa.*
Benjamin, Morton, *Big Island, Va.*
Berman, Harold B., *Brooklyn, N. Y.*
Biedler, William Thomas III, *Baltimore, Md.*
Brockmiller, Charles A., *Monaca, Pa.*
Buchholz, Richard F., *Baton Rouge, La.*
Bush, Martin H., *Beaver, Pa.*
Cantwell, Kenneth R., *Bartlesville, Okla.*
Cheshire, John R., *La Porte, Tex.*
Christopher, Robert G., *Brooklyn, N. Y.*
Cooperman, I. N., *Charleston, W. Va.*
Daly, William G., *Verona, Pa.*
Davis, Richard, *Webster Groves, Mo.*
Deitrick, Ashton D., Jr., *Belle, W. Va.*
Divilbiss, Richard J., *So. Charleston, W. Va.*
Dobson, Chris E., *Wilmington, Del.*
Eccles, Edwin J., Jr., *Nitro, W. Va.*
Englund, Stanley M., *Midland, Mich.*
Frank, Otto, *Stamford, Conn.*
Gangloff, Robert C., *Barberton, Ohio*
Garrett, James E., *Chihuahua (Chih), Mexico*
Garrick, Henry, *Pittsburgh, Pa.*
Haller, Allen K., *Portland, Ore.*
Hildebrand, Arthur C., *Dundalk, Md.*
Hjersted, N. B., *Independence, Mo.*
Hoffman, George M., *New Castle, Del.*
Hoglund, Earl B., *Wilmington, Del.*
Holland, Edward J., *Pampa, Tex.*
Huckins, Howard E., Jr., *New Castle, Del.*
Jones, J. Barry, *Corpus Christi, Tex.*
Jones, Robert A., *Tonawanda, N. Y.*
Kalb, Walter G., *Beaver, Pa.*
Kazanowski, Albin D., *Cambridge, Mass.*
Kenner, Alex T., *Stratford (Ont.), Canada*
Krus, Aaron, *Pasadena, Tex.*
Larson, George P., *Arlington, N. J.*
Logan, Robert P., *Stamford, Conn.*
Lombardi, P. Joseph, *Ozone Park, N. Y.*
Lombardo, Rosario Joseph, *Charleston, W. Va.*
Longmire, David R., *Detroit, Mich.*
McCarthy, Michael J., *Buffalo, N. Y.*
Miller, J. William, *Midland, Mich.*
Mooney, Richard S., *Drexel Hill, Pa.*
Moretz, George E., *Maryville, Tenn.*
Newsom, B. I., *Texas City, Tex.*
Norris, William L., *Wadsworth, Ohio*
Olson, Edwin A., *Wilmington, Del.*
Olson, Roy N., *Chicago, Ill.*
Pennucci, John A., *Akron, Ohio*
Petersen, Peter J., *Chicago, Ill.*
Pfander, John E., *Wilmington, Del.*
Phelan, James R., *Trenton, Mich.*
Popovac, Daniel O., *Ponca City, Okla.*
Reinmuth, Gene K., *Borger, Tex.*
Sample, Norris L., *Monsanto, Ill.*
Saunders, James A., *Newark, Del.*
Schmitt, Richard W., *Pittsburgh, Pa.*
Seibert, Charles A., Jr., *Long Beach, Calif.*
Sirockman, John S., Jr., *Morgantown, W. Va.*
Stallmann, Werner M., *Rockville, Ind.*
Stern, Daniel, *Baltimore, Md.*
Sullivan, F. W., *Wallingford, Pa.*
Supnik, Ross H., *Springfield, Mass.*
Taylor, Clayton M., *Terre Haute, Ind.*
Timm, Herbert M., *Topeka, Kans.*
Updegrove, Robert C., *Texas City, Tex.*
Vosseller, George V., *Niagara Falls, N. Y.*
Voznick, Henry P., *Cincinnati, Ohio*
Wade, William W., *Monsanto, Tenn.*
Walther, George F., *So. Charleston, W. Va.*
Westerfeld, George C., *LaPorte, Tex.*
Whildin, William M., *Buffalo, N. Y.*
Zachariou, Renos S., *Texas City, Tex.*
Zeitlin, Harold R., *Chicago, Ill.*
Ziccarelli, John J., *Woodbury, N. J.*

A.I.Ch.E. TO PARTICIPATE IN 1952 CENTENNIAL

APPROXIMATELY 50 national and international engineering organizations will support the objectives of the United States Centennial of Engineering in 1952, which will coincide with the one-hundredth anniversary of the founding of the American Society of Civil Engineers. Engineering societies and institutions of Western Europe, Great Britain, Central and South America are expected to attend. Although the celebration is nationwide in scope, the major events will take place during the summer and early fall in Chicago, at the Museum of Science and Industry and at various leading hotels, including the Stevens, Palmer House, Edgewater Beach, and the Sherman.

The Centennial's two principal functions will be the Exposition, highlighted by a summer-long pageant, and a Convocation to be held Sept. 3-13, 1952. The Exposition, which will be installed in the Museum of Science and Industry, will supplement the present collection of exhibits considered to be one of the finest in the fields of science, engineering and industry. Leaders in all branches of the engineering profession will be responsible for the new exhibits which will be opened to the public in July, 1952, free of charge and remain for at least five years.

The Convocation, the culminating feature of the Centennial, is expected to bring together the world's outstanding engineers. This program will give the engineer the opportunity to hear discussions in his particular branch of the profession and to attend sessions devoted to other fields and techniques of engineering. Symposium sessions, covering broad fields of engineering and industrial accomplishment, are scheduled for each day throughout the ten-day period. While the subjects will cover a variety of engineering and industrial accomplishments, the presentations will be sufficiently nontechnical to be of educational value to the general public. In addition there will be technical meetings arranged by the individual societies as well as joint sessions on subjects in which two or more societies have a mutuality of interest.

A special not-for-profit corporation, Centennial of Engineering, 1952, Inc., has been created to direct the over-all phases of the convocation. The American Institute of Chemical Engineers will be one of the participating societies. Members of A.I.Ch.E. on the board of directors include T. H. Chilton, 1951 President of A.I.Ch.E. and technical director, engineering department, Du

(*Continued on page* 49)

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INSTITUTE NEWS

ANNUAL REPORT OF COUNCIL

THIS report of the actions of the Council of the Institute covers the period Nov. 1, 1950 to Nov. 1, 1951. During this period there were eight (8) meetings of Council held in the months of November, December, January, February, March, May, September and October, and thirteen (13) meetings of the Executive Committee, one in each month of the year and two in the month of January. All these meetings have been reported in considerable detail in Chemical Engineering Progress, therefore this report is a summation of the actions taken during the year.

Membership. It is indeed gratifying to report again this year that the increase in membership of the Institute has continued at a satisfactory rate. In fact, the total number of new members is appreciably higher than it was last year. The number of new members elected was 1,354 compared with 1,043 in 1950 and 1,154 in 1949.

Other factors which affect membership are resignations, loss of members through non-payment of dues, and loss of members through death; the total of these is about the same as a year ago, thus our net increase in membership is 1,008 against a net figure of 657 for 1950 and 821 for 1949. The figures from which the above is derived are given in the accompanying tables.

Publications. The official publication of the Institute has continued to be "C.E.P." The year's operations have shown a satisfactory improvement over 1950. Subscriptions have increased and it would appear now that the magazine is established and we can expect to operate on a self-supporting basis with subscription assistance from the membership of the Institute, namely, the $4.50 of dues which are allocated to the magazine.

During the latter part of this year the first of the Institute Lecture Series has been made available, which is a 74-page book on Reaction Kinetics in Chemical Engineering by Olaf A. Hougen of the University of Wisconsin who was the second of the Institute Lecturers. No publication has resulted from the first Lecture by W. H. McAdams on Heat Transfer.

There are also copies of the first of the Symposium Series publications which is the one on Ultrasonics. This publication of 87 pages is the result of two symposia on this subject.

The Institution of Chemical Engineers (London) has still been experiencing difficulty in getting up to date on back issues of its Transactions. This is partly due to a change in its publication policy which is explained to the members fully in a notice which will accompany the 1952 dues bill.

Copies of the 1948 Transactions of The Institution were distributed during the year. The first shipment of the 1949 Transactions has been received in this country and will be available for distribution in the near future to those who ordered it. It is expected that the 1950 Transactions will be available early in the coming year.

Meetings. Four meetings of the Institute were held during the period of this report: The 1950 annual meeting at Columbus, Ohio, Dec. 3-6, a meeting at White Sulphur Springs, March 11-14, one at Kansas City, May 13-16, and another at Rochester, Sept. 16-19. The attendance at these meetings has been gratifying and has shown a general increase each year.

Bylaws. The Constitution and Bylaws Committee has been active during the year in the preparation of a set of revised bylaws. These are nearly completed and it is expected that they will be available in time for inclusion in the Year Book for 1952.

Accrediting. The Chemical Engineering Education and Accrediting Committee has had an active year which resulted in the addition to the list of accredited curricula of the chemical engineering curriculum at Kansas State College, University of North Dakota, Villanova College and the State College of Washington. Actions of the Council of the Institute in connection with accrediting have been reported to the Engineers' Council for Professional Development and they have taken a like action so again the lists of accredited chemical engineering curricula of the Institute and ECPD are the same.

Awards. The several awards of the Institute were presented at the Awards Dinner at the annual meeting in Columbus. E. R. Gilliland of Massachusetts Institute of Technology received the Professional Progress Award in Chemical Engineering for outstanding contributions in the field of chemical engineering and he also was the main speaker at the Dinner. The William H. Walker Award was presented to B. F. Dodge of Yale University in recognition of his excellent publications in the fields of Thermodynamics and Gas Absorption and especially for his part in the low temperature process for oxygen production. The Junior Award, which is presented in recognition of the best paper published by the Institute of which the sole author, or authors, is a Junior Member of the Institute, went to F. M. Tiller of Vanderbilt University for his two papers, "Stagewise Operations-Graphical Solution of Difference Equations," and "Efficiencies in Gas Absorption, Extraction, and Washing."

The awards for the Student Problem Contest were also presented at this Dinner and the recipient of the First Prize, the A. McLaren White Award, was Robert P. Bannon of the University of Illinois; winner of the second prize was Leonard R. Brooks of the University of Oklahoma; winner of the third prize was Charles E. Wicks of Oregon State College. There were three Honorable Mention Awards which were received by Herbert L. Stone of Rice Institute, and Sanford Baranow and Lawrence Ansell of Clarkson College of Technology.

The Scholarship Award program was continued throughout the year. This is an award in recognition of scholastic attainment during the freshman and sophomore years of the chemical engineering curricula at those institutions in which the Institute has student chapters. The award consists of a certificate, a Student Membership, a Student Member Pin, and a two-year subscription to "C.E.P."

The Council has continued to encourage the holding of Regional Student Chapter Conferences at which papers are presented by students from the various institutions represented. A certificate is awarded to the author of the paper judged to be the best and the same prize is given for the second best paper. In addition to the certificate, a one-year subscription to "C.E.P." is awarded.

Student Chapters. Two new student chapters have been authorized during the year, one at Stanford University and another at Seattle University, which brings the total number of student chapters as of Oct. 31 to 96.

The Student Chapter News has been continued and has also been authorized by Council for continuation in the coming year.

Jan. 1, 1951 marked the beginning of Student Membership in the Institute and we are pleased to report that there were 2,303 Student members. The special privilege extended to these members of subscribing to "C.E.P." at $3.50 was an attractive offer to 1,156 of the Student members.

Local Sections. One new local section located at El Dorado, Ark., has been authorized during the year. As far as has been possible officers of the Institute have arranged to attend meetings of local sections and the plan is that this activity will be continued and we

(*Continued on page 38*)

Membership	Active	Associate	Junior	Total
Nov. 1, 1950	3,966	475	5,927	10,368
Elections	396	121	837	1,354
Deceased	20	1	2	23
Resigned	6	8	69	83
Dropped	37	10	161	208
Elections Rescinded	1	1	30	32
Nov. 1, 1951	4,298	576	6,502	11,376

	1950		1951		1951-1950 Increase	
Membership	No.	%	No.	%	No.	%
Active	3966	38.2	4298	37.8	332	8.4
Associate	475	4.6	576	5.1	101	21.3
Junior	5927	57.2	6502	57.1	575	9.7
Total	10,368	100.0	11,376	100.0	1008	9.7

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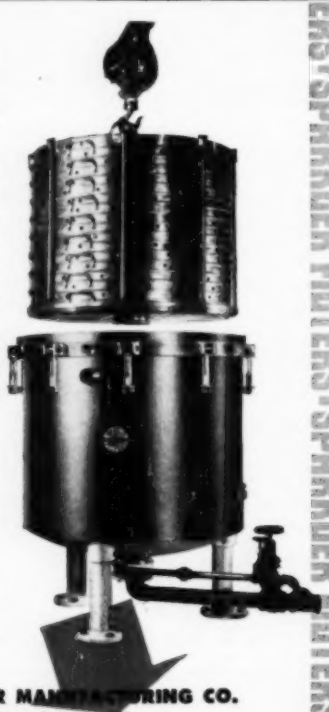

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COUNCIL REPORT

(*Continued from page 36*)

hope that it may be increased appreciably.

Activities with Other Groups. Cooperation with other groups in the engineering field has continued to be an important activity of the Institute. The most outstanding activity of the year has been the establishment of the Engineering Manpower Commission of the Engineers' Joint Council. This is a joint activity of the five engineering societies and the American Society for Engineering Education. An office has been established at 29 West 39th Street, New York, and a staff has been actively accumulating information and has distributed a great deal of this extensively throughout the country. Their activity has also included contact with the Defense Department in connection with the problem of proper handling of men in reserve status. In addition to this, the information collected has been of considerable use in formulating policies within the Selective Service System both for the proper handling of the cases of graduates and undergraduates. Reports, bulletins, and other information of the Engineering Manpower Commission have been circulated to the local sections of the Institute with the recommendation that they give this as much publicity as possible, perhaps making a report at each meeting.

Another important committee of the EJC is the International Relations Committee, which has during the year concerned itself with cooperation with other groups outside the United States, particularly in Europe through the Conference of Representatives of the Engineering Societies of Western Europe and the United States, and in South America and Mexico through the Union of Pan American Engineering Societies. Your Secretary attended the organization meeting of UPADI at Havana in April of this year and has been serving since that time on the Constitution and Bylaws Committee.

Another far reaching activity of EJC has been the study of the water resources of the United States and preparation of a report which has been given considerable distribution. Furthermore, this Committee studied the Water Policy Report prepared by the President's Water Resources Policy Commission and a Critique was prepared on this. Our representatives on the EJC have been W. L. McCabe, F. J. Curtis, T. H. Chilton and your Secretary, with D. B. Keyes acting as alternate. T. H. Chilton will be the vice-chairman of EJC for 1952 and it is expected that he will be the chairman for 1953.

Another activity of the Institute has been in connection with the activities of the Engineers' Council for Professional Development of which the Institute has been a member since its formation in 1932. There are several important committees of ECPD, namely, the Committee on Employment Conditions for Engineers, Committee on Guidance, Committee on Principles of Engineering Ethics and the Committee on Professional Recognition. The recently formed Committee on Student Development will devote its attention to the relations between the engineering schools, the engineering societies and industry for the

(*Continued on page 44*)

Chemical Engineering Progress

DATA SERVICE

CHEMICALS

1 • BOTANICALS, CHEMICALS, & INSECTICIDES. A catalog of botanical drugs, chemicals, insecticides, concentrates and rodenticides from the Prentiss Drug & Chemical Co., of 250 substances giving trade, generic names and common usage. Catalog also covers insecticide and rodenticide compounds, describing actions.

2 • VINYL ACETATE COPOLYMERS. Custom-made formulations to meet user's requirements are available from National Adhesives Division of National Starch Products, Inc. Applications of vinyl resin solutions in adhesive formulations, laminations, greaseproof coatings, high solids lacquers, etc. Available in large range of molecular weights, various solvents, concentrations ranging from low to unusually high solids content.

3 • PROPANEDIOLS. From Carbide & Carbon Chemicals Co., two new diols, 2-ethyl-2-butyl-propanediol-1,3 and 2,2-Diethyl Propanediol-1,3. Technical bulletin describes physical, chemical, and physiological properties and possibilities, one being that of an insect repellent since lower vapor pressure makes it last longer than other repellents. Other new diols are also described.

4 • TALL OIL IN EMULSIONS. Bulletin published by the Tall Oil Assoc., describing use of tall oil in emulsions. Covers types of emulsifiers, methods and equipment for making emulsions, uses, etc.

5 • TANK CLEANER. For cleaning aluminum tanks, Turco Products, Inc., announces a noncorrosive, nonetching cleaner. Quick rinse.

6 • ACRYLIC RUBBERS. Two new acrylic rubbers, Acrylon BA-12 and Acrylon EA-5 by American Monomer Corp. Originally pioneered as Lactoprene rubbers by the Eastern Regional Research Laboratory. BA-12 shows good, low-temperature characteristics and is resistant to heat, hot oils, boiling water, oxygen, ozone, and sunlight. EA-5 has somewhat less low-temperature flexibility but increased oil resistance.

7 • POLYESTER LAMINATING RESIN. Naugatuck Chemical's new laminating resin to withstand temperatures as high as 500° F. Retains laminates of resin in glass fabric. Flexural strength between 40,000 and 47,000 lbs./sq.in. when exposed 200 hrs. at 300° F. Heat-resisting properties due to triallyl cyanurate. Physical data, general properties, electrical, and other characteristics.

8 • SURFACE-ACTIVE AGENT. Aerosol SE new with the American Cyanamid Co. as a detergent, rewetting, and surfactant for textile, paper, plastic industries. Material is quaternary ammonium compound. Active in acid media, hard water, salt solutions, etc. Uses explained.

9 • TRIALLYL CYANURATE. New product bulletin of American Cyanamid Co. on triallyl cyanurate for use in the pharmaceutical, pest control, and chemical fields. Bulletin gives physical properties, absorption spectrum, stability reactions, chemical properties, and potential applications. Toxicity and bibliography included.

10 • VINYLTRICHLOR AND VINYLTRIETHOXY SILANES. A Linde Air Products Co. data sheet on above compounds. Physical properties, chemical reactions, applications, availability, and safety precautions. Can be used as a sizing agent for heat-cleaned glass cloth, for polyester laminates, for protective coatings in the plastic, textile, and chemical fields.

11 • FUNGICIDE AND WATER REPELLENT. A compound containing copper 8-quinolinolate which combines mildew resistance with water repellency is new with Nuodex Products Co. as Quindex W.R. 10%. Used in the proofing of cotton duck, twill, and other textiles to meet government specifications for tents, packboards, etc.

12 • SULFUR SUBSTITUTE. To replace elemental sulfur in natural and synthetic rubber furnace black stock, Monsanto Chemical Co. has developed 4,4'-dithiodimorpholine, trade name Sulfasan R. Reduces scorch in high modulus and high abrasion furnace black stocks. Sulfur content of stocks with the new compound is half that with free sulfur.

14 • DIAMINO DIPHENYL SULFONE. As an intermediate in the production of dye stuffs, and base for ion-ex-

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change resins, Monsanto Chemical Co. data on diamino diphenyl sulfone. Gives formulation, physical & chemical properties, reactions, applications, and bibliography.

16 • *HANDLING METALLIC SODIUM.* Illustrated book on handling metallic sodium, National Distillers Chemical Corp. Discusses safe handling of metallic sodium from 1-lb. bricks to 80,000-lb. tank cars. Covers use of sodium in industry, properties of metallic sodium, methods of shipping, commercial specifications, diagrams of tank car and loading systems, how to clean process equipment, safety precautions and first aid, describes protective clothing, etc.

17 • *PLASTICIZER CATALOG.* Carbide & Carbon Chemicals Co. 76-page book on Flexol plasticizers. Describes properties, and applications in plastics, coatings, and rubber compounds. Covers dozen different plasticizers, has plasticizer selector chart for various resins. Gives physical properties of each plasticizer. Well illustrated, gives physical data on performance, etc. Dispersions also covered.

BULLETINS

22 • *CONTROLLED VOLUME PUMPING.* Milton Roy with extensive bulletin on motor-driven controlled-volume pumps. For use with liquids from heavy viscous to light solvents, solids in suspensions, abrasive slurries, etc. Reciprocating positive, displacement plunger-type pump. Booklet describes all models, gives capacity-pressure charts, materials of construction, explains principle of operation, capacity regulation, etc. Capacity-pressure tables included, plus dimensions, etc.

23 • *TUBES & PLATES.* From the American Brass Co. a new and expanded edition of "Anaconda Tubes and Plates for Condensers and Heat Exchangers." Discussion of application, construction, tube alloys available and their uses, plates for tube sheets and baffles for heat-transfer equipment. Manufacturing methods, installation data, operational factors, corrosion, etc. Of primary interest to chemical engineers designing or working with heat exchangers.

24 • *VENTILATING EQUIPMENT.* Descriptive brochure on ventilating and duct-type fans by the L. J. Wing Mfg. Co. Specifically discussing Wingfoil duct fan. Pics. of installations, types, tables of dimensions, capacities, etc.

25 • *FILTER.* A brochure on the Hercules Filter Corp.'s self-cleaning pressure-leaf filter for use with any type of filter material—fibrous, granular, powder, or woven. Cylindrical type with filter leaves suspended vertically inside on a centrally located discharge pipe. Operation sizes, advantages, explanations of complete system in bulletin.

26 • *STEAM COST SLIDE RULE.* A slide-rule calculator for computing steam cost is offered by Cleaver-Brooks Co. Enables calculation in comparative steam costs between coal, oil, or gas. Accounts for system efficiency.

27 • *ALUMINUM PETROLEUM EQUIPMENT.* An abstract of a paper from the proceedings of the A.P.I. on "The Use of Aluminum in Petroleum Refinery Equipment." Description and evaluation of the metal in petroleum usage.

28 • *METAL PRIMER.* A technical data sheet on a heavy-duty, rust-inhibitive primer from the Prufcoat Laboratories, Inc. For either ferrous or nonferrous metals. For conventional paints as well as active-solvent protective coatings. Primer has the application characteristics of zinc chromate or red lead. Effective over surfaces that are already corroded, spot priming, etc.

29 • *CHEMICAL EQUIPMENT.* A Read Standard Corp. bulletin on chemical process equipment covering bins, conveyors, elevators, sifters, weigh hoppers, mixers of seven different designs and Standardaire blowers. Tables of capacities for the blowers, as well as mixers.

30 • *CALIBRATION SERVICE.* A bulletin describing the Fischer & Porter Co. service to industry on calibration of flow meters. Explains the service covering all types of fluids under various conditions, such as refrigeration or heating, varying specific gravity, viscosity, etc. Twenty rigs are used to handle liquid flow from a fraction of a cubic centimeter to 2000 gals./min. Vapor and gas calibration also.

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31 • *STAINLESS STEEL ACCESSORIES.* A guide and reference book of stainless steel products by the Schnitzer Alloy Products Co. Products range from a small nut up to tees and elbows. Also equipment such as pumps, buckets, heating units, etc. Book covers type of stainless steel available, two pages of laboratory corrosion data, and tables of sizes, dimensions, weight, and price of all the accessories covered.

32 • *BELT CONVEYORS.* A new belt-conveyor carrier catalog by the Stephens-Adamson Mfg. Co. Carriers are rotating members over which belt travels. Illustrations of design, position, dimensions, widths, etc., for every type of belt-conveyor installation.

33 • *SCIENTIFIC APPARATUS AND METHODS.* A quarterly publication of E. H. Sargent & Co. devoted to the latest scientific methods of laboratory and analytical technique. The Fall edition contains Sargent's latest catalog revisions, plus discussion of a new mercury cathode vessel.

34 • *NEOPRENE COATING.* For protection against corrosive materials Gates Engineering Co. announced neoprene protective materials. Includes a lining, uncured sheetstock for heavy duty tank and equipment lining, a putty for filling joints, a surface preparation applied by brush or spray, a skidproof coating for safety walks, steps and ramps, and an aircraft coating. Bulletin lists products, applications, accelerator to use, surface preparation necessary, primer to use, thinner, how it's applied, cure necessary and the amount of coverage.

35 • *OBERDORFER PUMPS.* A catalog of bronze pumps made by the Oberdorfer Foundries, Inc. Covers rotary gear pumps, including a new unit which is close-coupled, a pump housed in a machined block of carbon for highly corrosive installations, unit with a rubber impeller, plus a description of their standard series. Capacity tables for various speeds and outlet pressures included.

36 • *PNEUMATIC TEMPERATURE CONTROL.* Control from Burling Instrument Co. which is pneumatic in operation. For maximum temperatures of 1400° F. with standard tubes or 2000° F. with special tubes. Unit acts to cut off fuel supply in tank or oven when temperature exceeds limit.

37 • *FILTERS.* A leaflet from the Eimco Corp. explaining general line of filters and application to industry. Explains general Eimco organization, technical assistance on filtration problems and illustrates installations in industry.

38 • *SACKING SCALES.* A line of scales to sack and weigh at the same time in a bulletin from the Exact Weight Scale Co. Six models are described and general specifications are listed. Feature: scale set so material in fall is accounted for when pointer registers exact weight. Eliminates bag trim by operator.

39 • *GLASS-LINED ACCESSORIES.* A bulletin describing Pfaudler's heavy duty glass-lined pipe, valves, and fittings for chemical operations. Standard pipe lined with acid-resistant glass from 1½ to 12 in. Larger sizes on order. Heat exchangers with multiple inlet and sight boxes, flanges, valves, etc., are illustrated.

40 • *VALVES.* A description of Falcon-Greenwood valves. Vertical swing horizontal check valve, triple action safety quick closing valve, and combination check and plug valves. Stresses safeguarding of solvent and gas tank against fire by means of safety quick closing valves. Can be closed with either fusible links, plunger pressure, or manually.

41 • *HEATING COILS.* A description of a complete line of steam and hot water coils for the chemical field from the Trane Co. Catalog on capacities, selection, performance, installation and dimension data of coils which have a solderless bond. Shows construction features, methods of fabricating. Section devoted to selecting proper coils for heating, with data for selecting proper surface, number of tubes, etc., for given heat rise.

EQUIPMENT

50 • *INSULATION.* Hydrous calcium silicate insulation by the Kaylo division of Owens-Illinois Glass Co.

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Graphs, tables and drawings depicting heat insulation use. Industrial & commercial projects for temperatures up to 1200° F. Shows shapes and sizes available to insulate tubes, pipes, vessels, flat surfaces, etc.

51 • VACUUM DRYERS. Construction changes in Stokes vacuum shelf dryers announced by F. J. Stokes Machine Co. to give uniform heat throughout shelf area. Jacketed construction prevents condensation of vapors passing toward vacuum connection and other new features.

52 • CHROME PURIFIER. A portable unit by Illinois Water Treatment Co. for recovering and purifying chromic acid anodizing baths and reclaiming plating and rinse waters. Uses ion-exchange resins to effect recovery.

53 • SHAFT SEAL. A mechanical seal, a product of Cartriseal Corp. for use where shaft is affected by liquids. Resistant to most liquids and gases.

54 • TEFLON-TYPE BELLOWS. Where vibration, expansion or electrolysis exist Crane Packing Co. has developed a chemically inert Teflon bellows connector. Electrically nonconductive, flexible at −94° F. & can withstand temperatures at 480° F. Mounted between flanges in line.

55 • RADIOACTIVE STORAGE CABINETS. For storing radioactive samples a new cabinet by Nuclear Instrument & Chemical Corp. Sample holders are plastic cups, pressed into holes in the tray. Tray & holders can be replaced if contaminated.

56 • CLOTH-BAG DUST COLLECTOR. Pangborn Corp. with new cloth-bag collector for dusts such as carbon black, cork, graphite, pigments, soaps, etc. Sizes from 5 to 40 it. long, or 1,360 to 10,880 sq. ft. filter area. Features simplified design of filter bags and mechanism for reclaiming bag dust.

57 • UNIVERSAL pH METER. North American Philips Co. announces for industrial testing purposes a universal pH meter with measuring accuracy of .01 pH unit with a range of 0 to 14.15 pH. Can be used with glass, quinhydrone, hydrogen, and platin electrodes.

58 • SENSITIVE CHECK VALVES. For low-pressure applications, James-Pound-Clark line of ultrasensitive check valves. Cracking pressure is 4 to 8 in. of water, and will hold against back pressure to 100 lbs./sq. in. Sealing is through a poppet knife edge on an "O" ring.

59 • CO_2 RECORDER. Hays Corp. Co_2 recorder for determinations in large power plants. Combines in one instrument the use of CO_2 measurement as a guide to combustion efficiency, thermal conductivity principle and electronic operation. Bulletin available which illustrates and gives constructio.a details, advantages, operations, uses, etc.

60 • UTILITUBE. Aluminum Co. of America has trade-named Utilitube, a general purpose aluminum coiled tube of low cost per foot, easy workability and high fatigue strength. For use in fuel lines, air, vacuum systems, refrigeration, etc.

61 • COMBUSTIBLE-GAS ALARM. Explosion-proof combustible-gas alarm of Johnson-Williams, Ltd. for indoors or out. Indicate by lights or bells. Utilizes an electronic circuit to convert sensing-unit signals into alarm indications. For liquefied petroleum plants, chemical plants, gas plants, etc.

62 • V PORT GLOBE VALVE. For throttling service, a cast steel V-port globe valve with a special disc designed to regulate flow through four V-shaped ports. Product of Pacific Valves, Inc. Cast carbon steel with stainless steel trim indicator enables an estimation of the position of the disc. Available 1½ up to 6 in.

63 • SPRAY NOZZLES. Nonclogging spray nozzles for cleaning materials, screens, etc., described in Link-Belt folder. For cleaning coal, trash screens, sugar beets, scum-skimmers, etc., for pipes 1 to 3 in. in diameter. Charts give capacity and gal./min. at pressures of 20 to 100 lbs./sq.in.

64 • ARCTANGENT GRAPH PAPER. Graph paper having an arctangent scale and a linear scale, another with a double arctangent coordinate is announced by the Orbit Electric Co. Permits plotting uninterrupted curves of data having values ranging from + infinity to − infinity including zero. Asymptotic functions become linear. Typical plots are radioactive decay curves, heating and cooling curves. Technical bulletin explains theory and gives examples, plus sample of paper.

65 • FOAMGLAS INSULATION. Pittsburgh Corning Corp.'s new booklet on Foamglas insulation for piping and process equipment. Details sizes, thermal conductivity, properties, pipe spacing, shapes and thicknesses, applications, make for a complete data catalog on the use of Foamglas for insulation of hot, and cold, industrial equipment.

66 • SCALE-FREE PIPING. A new welding coupling consisting of two forged halves, which eliminates welding scale from piping systems is new with Tube Turns, Inc. Available in sizes from 1¼ through 12 in. in carbon steel. Specially designed for the process industries to carry chemicals, gases, hydraulic fluids, etc. Point of advantage is construction which prevents burn-through or formation of welding icicles in the interior. A circumferential cavity directly beneath the beveled welding area prevents the interior from extreme welding heat and scaling.

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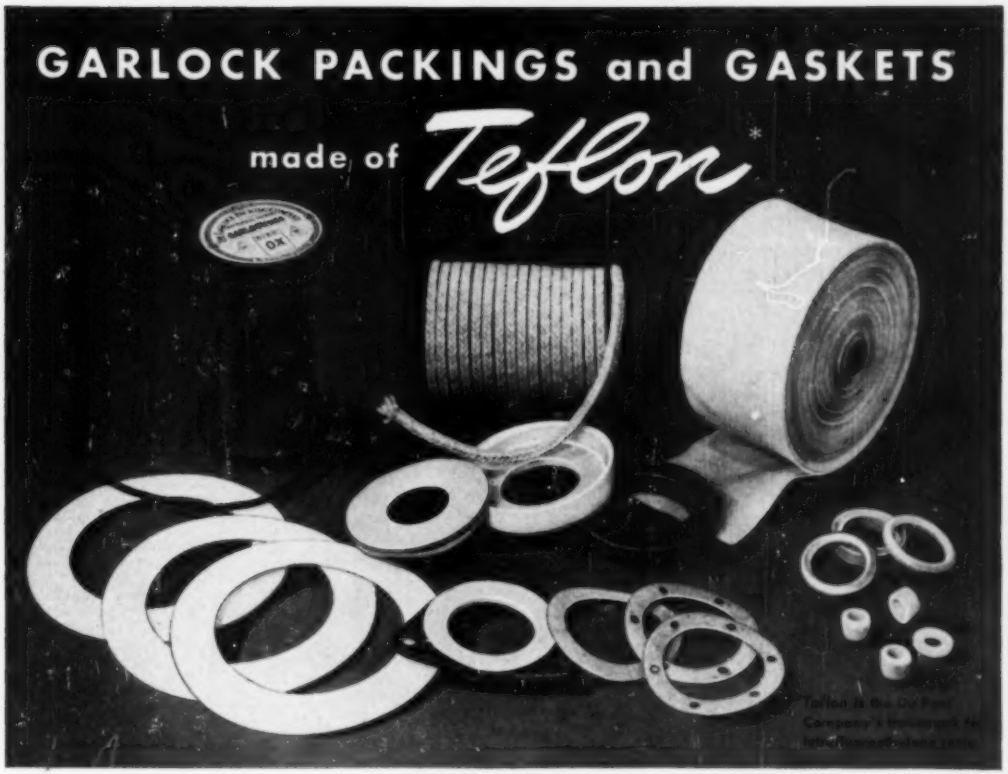
made of *Teflon**



*Teflon is the Du Pont Company's trademark for fluorocarbon resins

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GARLOCK packings and gaskets made of *Teflon* solve the problem of sealing against acids and chemicals of all kinds.

These *Teflon* products, fabricated in the GARLOCK factories, are unaffected by any acid and are highly resistant to all organic solvents and alkalies. They operate at temperatures from below −90° F. up to +500° F. and have high mechanical strength and a low coefficient of friction within that temperature range.

For use on valves, pump rods or shafts and any other equipment in the chemical industry, GARLOCK produces several types of braided and molded *Teflon* packings. For gasketing flanged joints of all kinds, including glass and porcelain flanges, *Teflon* envelope gaskets or solid *Teflon* gaskets are available in required sizes and shapes.

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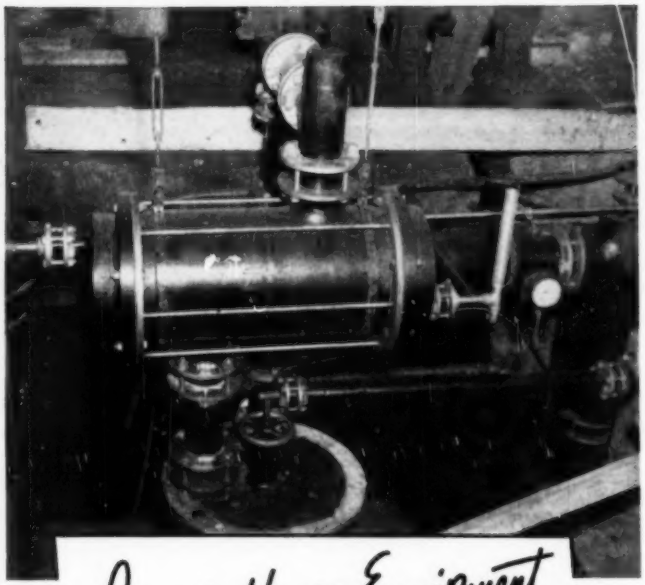

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COUNCIL REPORT

(*Continued from page 38*)

purpose of promoting the professional development of engineering students. Perhaps the most outstanding activity of ECPD up to the present has been its Committee on Engineering Schools now referred to as the Committee on Education which concerns itself solely with the accrediting of engineering curricula. It is with this Committee that our Chemical Engineering Education and Accrediting Committee cooperates fully. Our official representatives are P. D. V. Manning, W. N. Jones, and C. G. Kirkbride.

There has been a continued cooperation with several committees of the American Society of Mechanical Engineers, namely, the Air Pollution Control Committee, the Committee on Industrial Instruments and Regulators, Heat Transfer Division Coordinating Committee, Liaison Committee of Process Industries Division, Power Test Codes-Committee on Centrifugal and Rotary Pumps. We have had representation on the Joint Committee on Rating Refrigerating Equipment of the American Society of Refrigerating Engineers, Committee on Relations with Industry of the American Society for Engineering Education, on the Inter-Society Committee of Corrosion Engineers of the National Association of Corrosion Engineers, the National Engineering Advisory Committee, and with the National Research Council on their Conference on Glossary of Terms in Nuclear Science and Technology, and their Division of chemistry and chemical technology also their Division of Engineering and Industrial Research.

Our cooperation as a member of the American Standards Association while only in its second year has been an important activity. We have worked with them in the past in the establishment of Letter Symbols and Abbreviations for Chemical Engineering through their Committee, Z 10. At the present time, there is in progress the preparation of a standard set of Graphical Symbols and Abbreviations for Use on Drawings particularly in the chemical engineering field. Another committee of the ASA which is relatively new but quite active is the Chemical Industry Correlating Committee which concerns itself mainly with specifications for materials of construction for equipment. Other committees of the ASA in which we have been active are: the Safety Code Committee for Mechanical Refrigeration, the Standard Code Committee for Pressure Piping, the Committee on Allowable Concentration of Toxic Dusts and Gases, and the Safety Committee for Dry Cleaning Units.

The Council reports the passing during the year of the following members and in so doing expresses a feeling of real loss to the Institute: **Active Members:** A. P. Beardsley, N. G. Bradford, E. S. Cavett, A. R. Franck, E. H. French, S. L. Handforth, W. P. Heath, H. Howard, P. C. Kaiser, W. G. Krummrich, A. P. Lee, J. P. Maider, A. E. Marshall, F. H. Merrill, D. V. Moses, W. I. Nevius, E. E. Ware, J. N. Wickert, H. V. Wright. **Associate Member:** W. C. Frishe. **Junior Members:** M. T. Pawel and C. E. Shafer, Jr.

(*More Institute News on page 46*)

a new application of centrifugal force

Substantial savings in capital investment and operating costs for producers of electrolytic caustic soda . . . the result of a new Sharples Corporation development which makes use of a heretofore unexploited phenomenon—the solubility of "insoluble" sodium sulphate in brine, in a super gravitational field.

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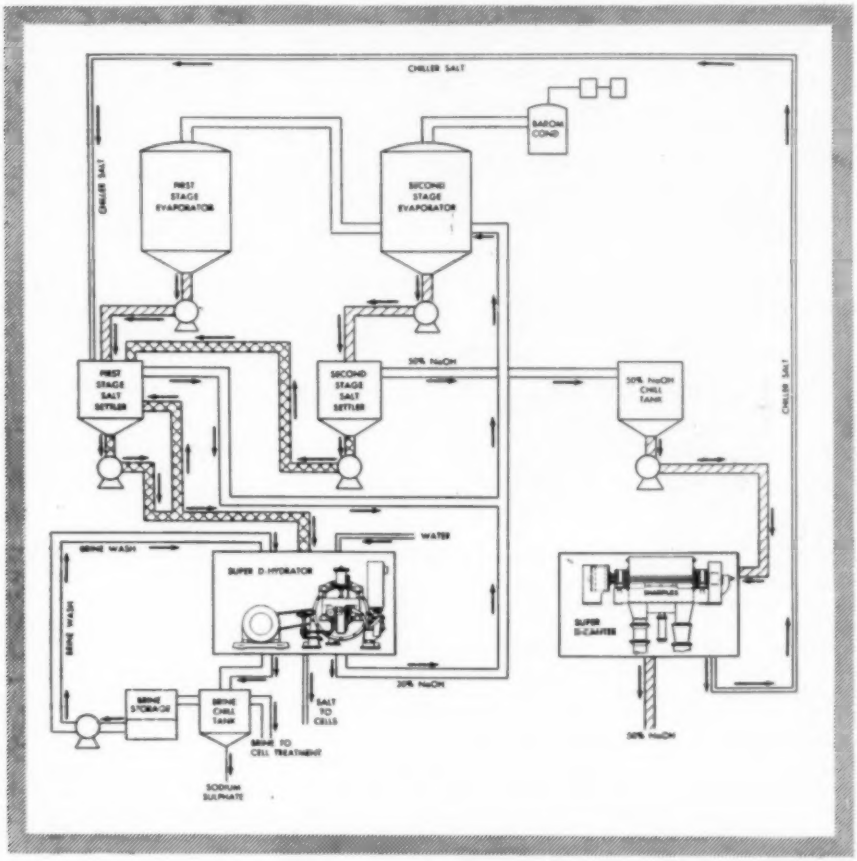

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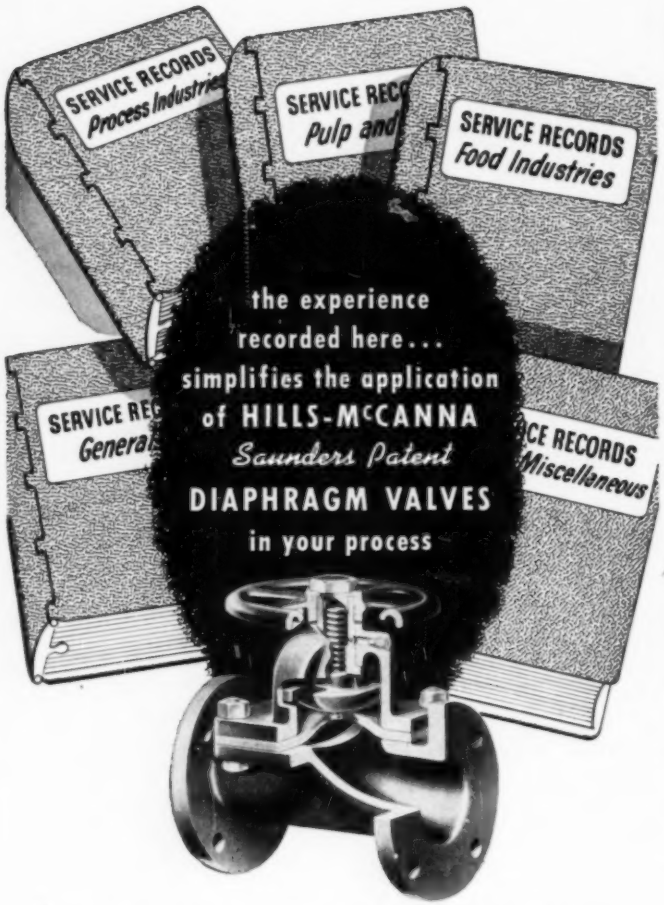

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Hills-McCanna Saunders Patent Diaphragm Valves are made in sizes from ⅜" to 14" for manual, automatic or remote operation with a choice of 13 diaphragm materials and 48 body materials. Write for complete information. HILLS-McCANNA CO., 2438 W. Nelson St., Chicago 18, Ill.

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Secretary's Report

S. L. TYLER

THE Executive Committee of the Institute met at the Haddon Hall, Atlantic City, N. J., Dec. 1, 1951. Minutes of the Nov. 7, 1951, meeting were received and approved with minor changes. Applicants for membership whose names appeared in the November issue of "C.E.P." were elected as of Jan. 2, 1952, to the grades of membership indicated.

Student members numbering 165 were elected for 1952 which obviously is only a part of those who will ultimately become Student members for 1952. Confirmation of the interim appointment of R. S. Aries as representative of the Institute at the 24th International Congress of Industrial Chemistry, Paris, Nov. 25-Dec. 1, 1951, was voted. Names of Paul F. Opitz, T. Ellis Peak, Jr., J. L. Fischer, J. E. Rothfleisch and H. E. Reichenberg were added to the Suspense List as these members had recently entered the Armed Forces. The following student chapter counselors were appointed upon recommendation of J. S. Walton, chairman of the Student Chapters Committee: H. D. Sims to succeed A. H. Cooper at Bucknell University, G. C. Szego as counselor of the new student chapter at Seattle University, and R. R. Paxton as counselor of the new student chapter at Stanford University.

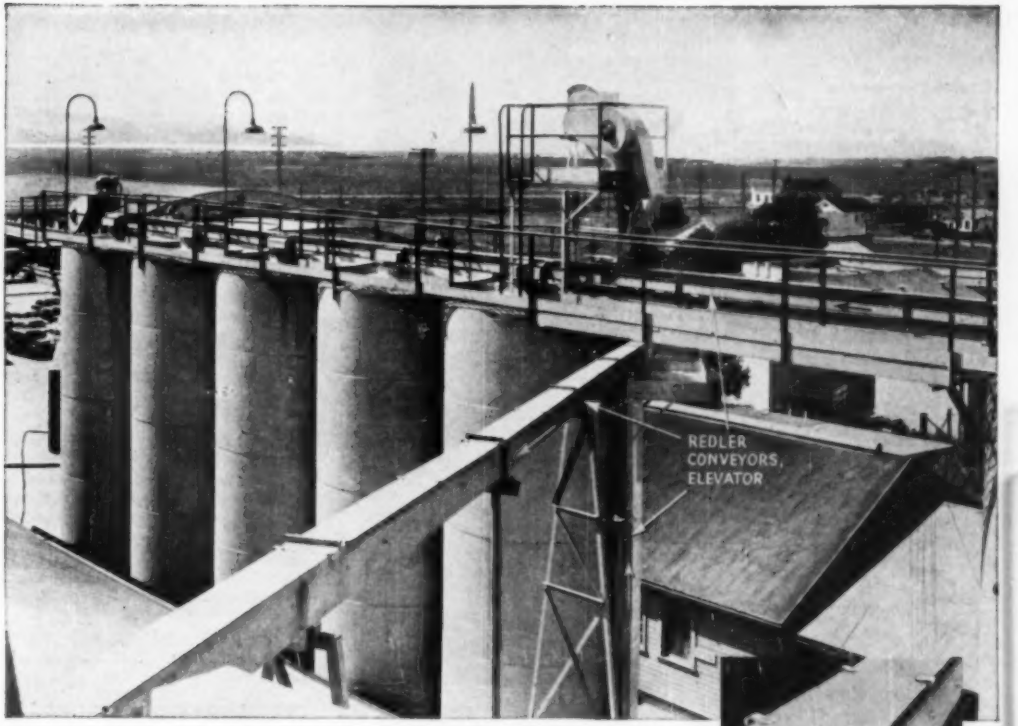
The Council of the Institute met at Haddon Hall, Atlantic City, N. J., Dec. 1 and 2. The meeting on Dec. 1 was devoted to a discussion with various committee chairmen of the activities of their committees and the future plans. This type of meeting is an innovation but was found to be satisfactory and educational and it is expected that at least one such meeting will be held annually in addition to committee chairmen appearing before Council at meetings when special matters are to be discussed.

The meeting on Dec. 2 was devoted to the regular agenda items. The Minutes of the Oct. 12 Executive Committee and Council meetings were received and approved as well as the Minutes of the Executive Committee meeting of Nov. 7.

The recommendations of the chairmen on membership of the various standing committees of the Institute were received and the appointments of committee personnel for 1952 made, also Institute representatives serving with other groups.

A budget for 1952 covering the activities of both the Institute and "C.E.P." was presented and accepted.

(*Continued on page* 48)



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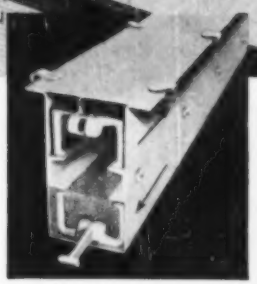
Insecticide chemicals handled to and from outdoor storage tanks must be fully protected against the elements, foreign materials and loss of volume. S-A engineers provided an installation of REDLER Conveyor-Elevators to assure volume handling with cleanliness, efficiency and economy.

For the past 50 years S-A engineers have dealt successfully with all types of bulk materials handling problems. They have a complete line of bulk handling equipment from which to recommend the exact type of equipment best suited for your needs. *Write for a free survey by an S-A engineer.*



CALIFORNIA SPRAY-CHEMICAL CORPORATION
Richmond, California

At this plant fine-mesh bulk chemicals are deposited in and withdrawn from eight outdoor steel storage tanks. Three REDLER Elevators lift material through enclosed casing to top of tanks and distribute it through a long, horizontal REDLER Conveyor. Other horizontal REDLER Conveyors reclaim chemicals below the tanks for delivery to processing operations. Through a gate-regulated, two-way chute, from the one elevator shown, chemicals may either be returned to the tanks or moved to the plant through the horizontal REDLER Conveyor shown in the foreground.

1901-1951
50 years experience with bulk handling
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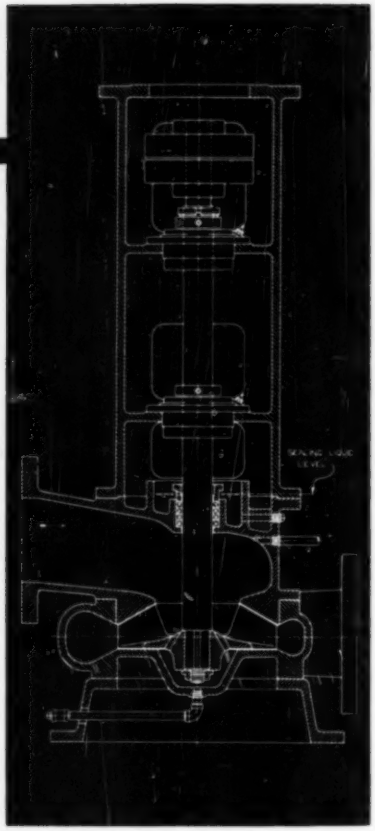
57 Ridgeway Avenue, Aurora, Illinois — Los Angeles, Calif. • Belleville, Ontario

DESIGNERS AND MANUFACTURERS OF ALL TYPES OF BULK MATERIALS HANDLING EQUIPMENT

Right: Cross-section of Lawrence Vertical Top Suction Pump for pumping volatile liquids.

Below: Vertical Top Suction Pump.



Pump VOLATILE LIQUIDS

— Under a Low Net Positive Suction Head (NSPH)
— Under a High Vacuum
— Without Air or Vapor Binding

When handling volatile liquids under a very low Net Positive Suction Head—from evaporators, for example — a horizontal pump is apt to become vapor-bound. Air or vapor binding is impossible if you install the Lawrence Vertical Top Suction Pump illustrated above. Extremely high vacuums are maintained by filling the space around the packing box with water or some other sealing liquid. The costly delays and shutdowns resulting from vapor binding and loss of vacuum are completely eliminated.

Lawrence Vertical Top Suction Pumps can be furnished in special resistant metals and alloys to handle the most corrosive and abrasive acids and chemicals.

Send for Bulletin 203-4 for complete summary of acid and chemical pump data.

LAWRENCE PUMPS

LAWRENCE
MACHINE & PUMP CORPORATION
375 MARKET STREET, LAWRENCE, MASS.

SECRETARY'S REPORT

(*Continued from page 46*)

Upon recommendation of C. E. Ford, chairman of the Local Sections Committee, it was voted to authorize the formation of the Terre Haute Section of the Institute with headquarters at Terre Haute, Ind.

The Council accepted with regret the resignation of R. L. Murray as a Director of the Institute, whose elected term had one year to run. Ralph H. Price of Texas City, Tex., was appointed to serve as a Director for this one year.

The Secretary presented the report of the Tellers' Committee and in accordance with the requirements of the Constitution, the Council declared the elected officers for 1952, Director for 1952, and Directors for a three-year term beginning Jan. 1, 1952, as follows:

President.....William I. Burt
Vice-President....William T. Nichols
Treasurer.....Carl R. DeLong
Secretary.....Stephen L. Tyler
Director for one year (1952)—
William T. Dixon
Director for three years, starting Jan. 1, 1952—J. Henry Rushton, Philip H. Groggins, Joseph C. Elgin, Arthur K. Doolittle

The Council voted approval of an Institute meeting to be held at Glenwood Springs, Col., in 1954.

TREASURER'S REPORT

The financial position of the Institute as to cash and bonds at Oct. 31, 1951, and compared with the previous year was as follows:

	1951	1950
Total bank balances	$109,794.98	$ 67,900.12
Negotiable bonds, face value	25,000.00	25,000.00
U. S. Savings Bonds, at cost	45,140.00	45,140.00
Total cash and bonds	$179,934.98	$138,040.12
Market value of negotiable bonds	$ 24,775.01	$ 25,467.19

Nov. 29, 1951 *C. R. DeLong, Treasurer*

ANTIQUITY OF CHEMICAL ENGINEER

D. D. Berolzheimer, chemical consultant and bibliophile, has called to the editor's attention what he believes is the earliest use of the term "chemical engineer." According to Dr. Berolzheimer, the Dictionary of Arts, Manufactures, and Mines, published in London in 1839, has on page 1220, a description of the construction of lead chambers for sulfuric acid manufacture. There the author says, "Provision should therefore be made against this event by the chemical engineer." This was printed in 1839, and should our readers know of any earlier use of the term, "C.E.P." would be glad to make note of it.

1952 CENTENNIAL

(*Continued from page 35*)

Pont Co., Wilmington, Del., E. R. Weidlein, president, Mellon Institute of Industrial Research, Pittsburgh, Pa., and Robert E. Wilson, chairman, Standard Oil Company of Indiana, Chicago, Ill.

Headquarters will be at the Museum of Science and Industry, whose president, Major Lenox R. Lohr, is also president of the corporation. Frank W. Edwards, on leave of absence from Illinois Institute of Technology, will coordinate the Centennial program. Charles F. Kettering, director and research consultant for General Motors, is chairman of the executive committee. E. L. Chandler, assistant secretary of A.S.C.E., has been named convocation manager. The heads of the two committees to coordinate activities of the numerous participating societies are Howard F. Peckworth, managing director of the American Concrete Pipe Association, Chicago, and G. Donald Kennedy, assistant to the president of the Portland Cement Association.

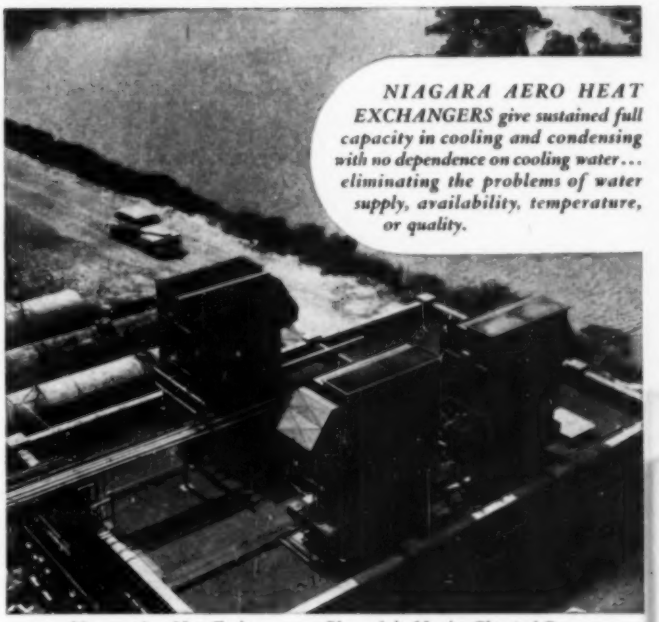
COLUMBIA INSTITUTES ENGINEERING CENTER

Many men in industry and the chemical engineering profession have endorsed plans for the new Columbia University Engineering Center, Dr. John R. Dunning, dean of engineering, said recently.

The Engineering Center will be located at Riverside Drive and 125th Street in New York. One building on the site is already partly occupied. Completion of the project is expected in time for Columbia University's bicentennial anniversary in 1954. A $22,150,000 fund-raising campaign to build, equip, and staff the Engineering Center is underway now.

The campaign program for its chemical engineering center opened with a dinner Dec. 5 at the Waldorf Astoria. Representatives of engineering societies, trustees of the University, and other professional and industrial leaders were guests of honor. Ex-President Herbert Hoover was the keynote speaker. Other speakers included Gen. William J. Donovan, special adviser to Gen. Dwight D. Eisenhower, university president; Dr. Grayson Kirk, vice-president-provost of Columbia; and Dr. John R. Dunning, dean of engineering.

The center will bring into a single organization three factors: engineering education, research, and practice. The plans provide for an Institute of Advanced Engineering Science and a Division of Cooperative Research in Engineering.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FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Atlanta, Ga., Atlanta Biltmore Hotel, Mar. 16-19, 1952.

Technical Program Chairman: H. E. O'Connell, Ethyl Corp., Box 341, Baton Rouge, La.

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.

Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Chicago, Ill., Palmer House, Sept. 11-13, 1952.

Technical Program Chairman: D. A. Dahlstrom, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.

Technical Program Chairman: R. L. Savage, Dept. of Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.

Technical Program Chairman: Norman A. Spector, Vitro Corp., 233 Broadway, New York 7, N. Y.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.

Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michigan, Ann Arbor, Mich.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

SYMPOSIA

New Types of Equipment for Use in Process Industries

Chairman: D. M. Considine, Market Extension Div., Ind. Div., Minneapolis-Honeywell Regulator Co., 7th and Grange Sts., Philadelphia, Pa.

Meeting—Atlanta, Ga.

Market Research

Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

Meeting—Atlanta, Ga.

Vacuum Engineering

Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Meeting—French Lick, Ind.

Distribution of Chemicals

Chairman: D. A. Dahlstrom, Northwestern University, Evanston, Ill.

Meeting—Chicago, Ill.

Human Relations

Chairman: R. L. Demmerle, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.

Meeting—Cleveland, Ohio.

Modern Statistical Methods in Chemical Engineering

Chairman: C. Daniel, Engineering Statistician, 116 Pinehurst Ave., New York 33, N. Y.

Meeting—Cleveland, Ohio.

Filtration

Chairman: F. M. Tiller, Dir., Div. of Eng., Lamar State College of Technology, Beaumont, Tex.

Chemical Engineering in Hydrometallurgy

Chairman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.

Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.

Fluid Mechanics

Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

LOCAL SECTION

TWIN CITY

New officers for this Section for 1952, elected Nov. 20, are as follows:

Chairman.....Jose Calva
Vice-Chairman.....William Podas
Secretary.....Russell Fredrickson
Treasurer.....Robert Bancroft
Directors—Fred Wehmer, Walter Carlson, Edgar Piret

At the Nov. 21 meeting the first speaker was Charles E. Matson from the quality control unit of Minnesota Mining and Manufacturing Co.'s tape department. Mr. Matson's talk was on "Variation," its mathematical meaning and its use in quality control of manufacturing.

Morris J. Root, research assistant of the Raymond Laboratories, St. Paul, gave a general picture of cosmetics research.

Reported by R. H. Fredrickson and J. B. Calva

OHIO VALLEY

The Dec. 3 meeting of this Section was held jointly with the Instrument Society of America and the American Institute of Electrical Engineers at the Engineering Society headquarters in Cincinnati. Following the dinner Ed. Mitsch, superintendent of electrical production at Cincinnati Gas and Electric Co., discussed "A New Power Supply for Cincinnati."

Philip E. Ohmart, president of the Ohmart Corp., gave the principal talk. He has discovered, it is claimed, a method of producing electric current from radioactivity. Some of the possible applications are to measure liquid level, pressure and vacuum, temperature, rates of corrosion, and the analysis of gases and alloys.

This Section's meeting on Nov. 5, 1951, was an inspection trip through the Hilton-Davis Chemical Co., manufacturers of pigments, dyes, and intermediates.

Reported by N. W. Morley

CHICAGO

Approximately 200 members and guests met at the Clearing Industrial Club Dec. 12 for a social hour and dinner. This was the third meeting of the season and it was the largest meeting of this Section.

Hobart P. Young, assistant superintendent of the fatty acid plant of Armour & Co., described the layout and special features of this new chemical plant which went into operation in 1948. Mr. Young's talk was brief to allow the group to make a tour through the plant.

Reported by Thorpe Dresser

EAST TENNESSEE

The 30th general meeting was held in the foremen's conference room, Tennessee Eastman Co., Kingsport, Tenn. Eight members were present. Lawrence Cox, director of Air Pollution Control for the City of Kingsport, spoke informally on "The General Aspects of Smoke and Fume Abatement." He outlined the general history of smoke abatement, and the cost of air pollution was reviewed briefly.

The work of the Air Pollution and Smoke Abatement Association of America was described. This organization is composed of people interested in air pollution control. Its fundamental purposes are the exchange of ideas between interested persons and the advancement of new or improved methods.

Reported by J. K. Pannill

EL DORADO

A dinner meeting, attended by 40 members and guests, was held at Dewey's Steak House in El Dorado, Ark., Oct. 26. Lewis H. Mahony, application engineer for the Mixing Equipment Co., Inc., Rochester, N. Y., presented a talk entitled "Mixing in Applied Chemical Engineering." Mr. Mahony discussed the design and application of agitated systems and provided a discussion of recent and potential developments in determining size, speed and impeller requirements for operations which require mixers. Two movies were presented that demonstrated the effect of impeller design and impeller position on mixing. A demonstration mixing tank was set up following the talk to show actual mixing effects.

Reported by R. L. Alexander

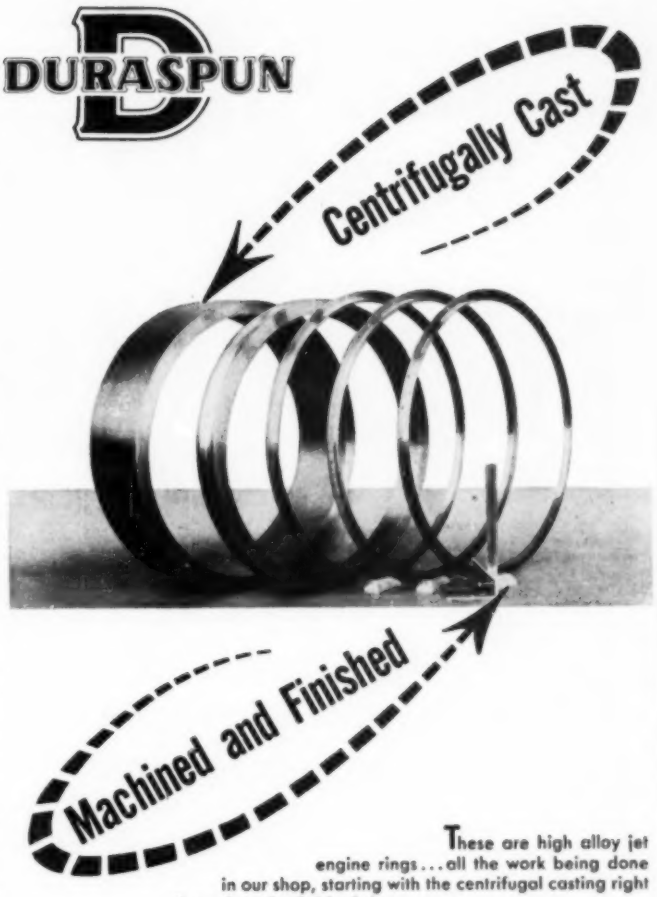
EASTERN CONNECTICUT CHEMICAL ENGINEERS' CLUB

This organization held its initial meeting Dec. 13, 1951, at Clark's Restaurant in Willimantic. The meeting was attended by 26 men. The speaker was Thomas H. Chilton, President of the A.I.Ch.E., whose topic was "Why is an Engineering Society." After adoption of bylaws the following officers were elected:

Chairman—Richard C. Berry, Rogers Corp.
Vice-Chairman—David H. Fields, American Thread Co.
Sec'y-Treas.—J. Lloyd McCurdy, Dow Chemical Co.
Executive Committee—Solomon Elmasian, Plastic Film Corp.; Kenneth E. Everett, Powdrell & Alexander; Raymond Rosenfield, New England Chemical Works.

Reported by R. C. Berry

(*More Local Section News on page 52*)



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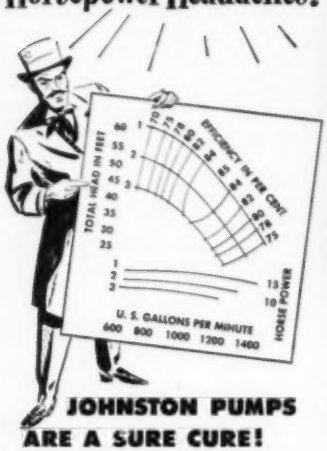

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LOCAL SECTION NEWS

(Continued from page 51)

NEW YORK

At the microphone shown above Jack Curran, regional director, United Gas, Coke and Chemical Workers, CIO, talked before the New York Section at the Brass Rail Restaurant, New York, Nov. 29, 1951. He covered the subject of union objectives and how unions operate, advantages to members, management relationships, and professional chemical unions. The other gentlemen in the picture are left to right: Warren H. Leverett, National Zinc Co., and Frank B. White, Foster Wheeler Corp.

CHARLESTON

The second meeting of this Section for the year 1951-52 was held Nov. 20 at the Charleston Recreation Center at which 121 members and guests were present. After the business session Thomas H. Chilton, President of A.I.Ch.E., addressed the meeting on the subject "Why Is An Engineering Society?" Dr. Chilton reviewed the purposes of engineering societies in general, and of A.I.Ch.E. in particular. He discussed first the activities which are directed toward the advancement of chemical engineering in theory and practice, including the several publications, the national and regional meetings, and the work of the national committees. He touched upon the standards for the three grades of membership in the Institute, support of the E.C.P.D., and participation in the E.J.C.

Reported by G. K. S. Connolly

NORTHERN CALIFORNIA

At the Dec. 17 meeting held in the Engineers Club in San Francisco Monroe E. Spaght, president of Shell Development Co., talked on "Selection and Planning—The Business in Research."

The 1951 directory contains in addition to a list of this Section's members their affiliations, a summary of 1950 meetings, and the bylaws of the Section.

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COLUMBIA VALLEY

The Nov. 27, 1951, meeting of this Section was held at the Lewis and Clark School in Richland.

Results of recent balloting on revisions to the bylaws were as follows:

1. It was voted to add a paragraph to the bylaws regarding the objects of the Section to encourage "The promotion of cordial and helpful relations with local engineering and scientific organizations for the social and professional benefit of all."
2. A line of succession for membership of the executive committee was approved.
3. The fiscal year was changed from a calendar year to one beginning June 1 with officers to be elected in May instead of December.
4. In agreement with (3) it was voted that the present officers remain in office until May, 1952.

The speaker of the evening was F. W. Schumacker, associate director of the process division, Standard Oil Development Co. His topic was "Fluidized Solids Technique and Its Application."

Mr. Schumacker gave a vivid picture of the fluidization process as applied to catalytic cracking in the petroleum industry. A model fluidizing apparatus of glass was used to demonstrate fluidization.

Reported by Carl F. Falk

TEXAS PANHANDLE

This Section held a meeting Dec. 10, 1951, at Phillips, Tex., with 42 in attendance.

The program for the evening included a talk titled, "Training of the Engineer in Industry," by L. P. Sumpter, superintendent of operating division, natural gasoline department, Phillips Petroleum Co. Mr. Sumpter expressed his views on the curricula for formal education and the need for further training in industry. Mr. Sumpter also covered the philosophy underlying the engineering training in industry and offered the group a basis for measuring one's personal success.

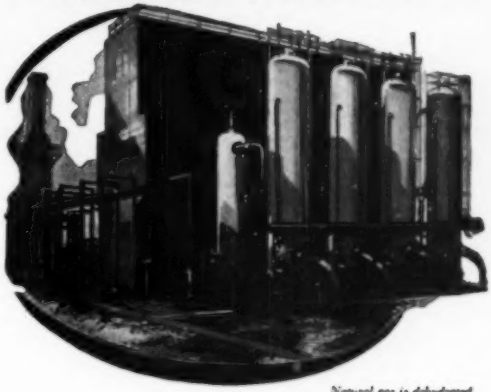
Reported by Henry W. Hennigan

PITTSBURGH

Development of the vinyl plastics industry is an outstanding example of technical advancement and chemical engineering at their best. This was the theme of an address by O. E. Isenburg, field sales manager of plastics materials, B. F. Goodrich Chemical Co., Cleveland, Ohio, before members of the Pittsburgh Section at the Dec. 5 dinner meeting, held at the College Club. Mr. Isenburg's subject was "Chemical Engineering Teamwork in the Vinyl Industry." A display of a wide range of

(*Continued on page 54*)

FLORIDIN ADSORBENTS



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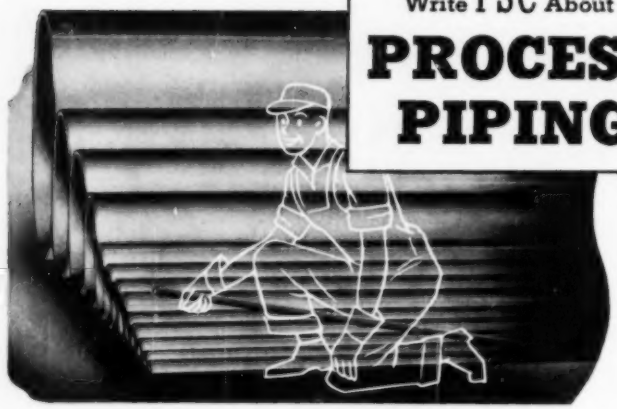

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LOCAL SECTION NEWS

(*Continued from page 53*)

vinyl plastic products and a motion picture film featured Mr. Isenburg's talk.

Reported by Hugh L. Kellner

ROCHESTER

The second meeting of the year was held Nov. 14, 1951, at Rundell Memorial Library. The speaker of the evening was Clifford C. Furnas, director of the Cornell Aeronautical Laboratory in Buffalo, N. Y. Dr. Furnas' talk covered many phases in the development of commercial, military, and private aviation and gave his predictions on where he thought these developments would lead. There were approximately 35 persons present at the dinner in honor of Dr. Furnas at Lorenzo's Restaurant, and about 60 present at the meeting.

Reported by Irving Siller

ST. LOUIS

A meeting was held at the York Hotel Nov. 20, 1951, at which 71 members and guests were present. They heard J. H. Rushton, director, department of chemical engineering, Illinois Institute of Technology, give a talk covering scale-up operations involving fluid motion at interfaces. Basic principles of dynamic similitude were reviewed and a general method was given whereby the requirements for dynamic similitude for any flowing system can be determined. Examples were given showing how these principles can be used in pilot plant models to obtain scale-up data for various unit operations.

Reported by A. T. Pickens

SOUTHERN CALIFORNIA

A meeting was held Dec. 18, 1951, at the Union Oil Co.'s Los Angeles refinery cafeteria in Wilmington. Raymond B. Stringfield, president, Fullerton Manufacturing Co., spoke on "Chemical Engineering in the Rubber Industry."

Reported by Gale S. Peterson

STUDENT CHAPTER AT STANFORD

Stanford University now has a student chapter of the American Institute of Chemical Engineers. Formal approval of the chapter, which formerly operated on a local basis as the Stanford Society of Chemical Engineers was granted late in 1951.

Officers of the new chapter are: Irenee May, chairman; Conrad von Bibra, vice-chairman; and John Trinastich, secretary. Professors Ralph R. Paxton and Carl G. Lindquist will be faculty advisers of the chapter.

PEOPLE

Robert L. Sommerville, assistant general sales manager of the Electric Storage Battery Co., Philadelphia, Pa., was recently elected president of the Association of American Battery Manufacturers at its annual convention in Chicago. Mr. Sommerville joined the New York office of the Electric Storage Battery Co. in 1919 and has held various sales executive positions since going to the Philadelphia office in 1932. He had previously been with the U. S. Government as an engineer on the locks and power plants of the Panama Canal.

Francis C. Frary retired as director of research, Aluminum Company of America, Jan. 1, 1952. Dr. Frary was the founder of organized research in the aluminum industry. Joining Alcoa in December, 1918, he organized Aluminum Research Laboratories at New Kensington, Pa. In 1915 he developed a process for manufacturing the war gas phosgene. During World War I, although Dr. Frary had already agreed to go to Alcoa, he was granted leave of absence upon the government's request to help build and operate the world's largest phosgene plant. When the war ended, Dr. Frary was a major in the Army's Chemical Warfare Service.

Dr. Frary studied analytical chemistry at the University of Minnesota, from which he was graduated in 1905. He received his M.S. there the following year. After a year's study at the University of Berlin he returned to Minnesota as instructor and later as assistant professor. He earned his Ph.D. degree in 1912.

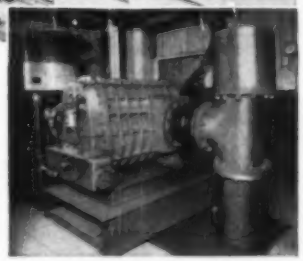
Dr. Frary holds more than 30 U. S. patents and is author of numerous books and papers on metallurgical and chemical subjects.

Richard O. Joslyn is now a sales engineer with the Layne-Western Co., Kansas City, Mo. Mr. Joslyn, who received his B.S. degree from Iowa State College, was formerly a chemical engineer with the National Carbon Co., Cleveland, Ohio.

Frank H. Bailey, formerly a chemical engineer in the explosives division of the American Cyanamid Co., New Castle, Pa., is now a development engineer for the Continental Can Co., Cambridge, Ohio.

(*More About People on page 56*)

Expansion at BRILLO includes: STANDARDAIRE BLOWERS



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PEOPLE

(*Continued from page 55*)

John D. Fennebresque was recently elected a vice-president of Celanese Corporation of America in charge of the chemical division, of which he has been general manager. He received the 1950 Award of the Yale Engineering Association for "advancement of basic and applied science." Mr. Fennebresque (Class of 1939) was cited for his work with Celanese in connection with the oxidation of natural gas hydrocarbons in the production of a long series of aliphatic compounds and his wartime work with the Office of the Rubber Director. Before going to Celanese he was affiliated with the Monsanto Chemical Co., St. Louis, Mo.

Homer R. Duffey, formerly general manager of the chemicals department of the Quaker Oats Co., Chicago, Ill., was recently appointed a vice-president of the company. Dr. Duffey, who received his Ph.D. from the University of Illinois, was previously with the Vulcan Copper & Supply Co., Cincinnati, Ohio.

Harry L. Pelzer, who early last year was appointed manager of the newly formed Sinclair Research Laboratories at Harvey, Ill., has been elected a director of the corporation. Mr. Pelzer joined the Sinclair organization in 1919 at the East Chicago refinery, in 1921 he was transferred to the research department as a chemical engineer, and in 1930 he was assigned to the Houston refinery as assistant superintendent. After several supervisory positions, he was transferred to the company's new laboratories in Harvey, Ill., as assistant manager until his promotion of last year.

J. Fred Dudley, who has been appointed chief engineer of Commercial Solvents Corp., New York, N. Y., will make his headquarters in Terre Haute, Ind. Mr. Dudley joined the company in 1943 and was appointed assistant chief engineer in February, 1951.

Frederic W. W. Hammersfahr, formerly with the General Tire and Rubber Co., Akron, Ohio, has been appointed head of General Electric's Chemical Process Development Laboratory in Pittsfield, Mass. Mr. Hammersfahr, who received his M.S. in chemical engineering at Massachusetts Institute of Technology, was previously with the Du Pont Co. as a development engineer.

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Jerome T. Coe, of the chemical division of the General Electric Co., Pittsfield, Mass., has been appointed customer service supervisor for silicone products at the company's office in Waterford, N. Y. Mr. Coe, who came with the company in 1942 shortly after receiving his B.S. degree from Massachusetts Institute of Technology, was previously in charge of the plant's process development section.

L. Vernon Larsen of General Electric's chemical division has been appointed engineering section head of G-E Textolite industrial and decorative laminates at the Coshocton, Ohio, plant. In this capacity, Mr. Larsen will remain in charge of the development section and also assist in personnel recruiting.

Charles B. Roen, formerly project engineer in the general engineering department, has been appointed a development chemical engineer in the general development department of the Monsanto Chemical Co., St. Louis, Mo. Mr. Roen was previously a technologist for the Shell Chemical Co.

John E. Gray is now director of the technical and production division, Atomic Energy Commission, at the Savannah River Plant, Wilmington, Del. He was formerly materials engineer in the Nuclear Power Division, Bureau of Ships, U. S. Navy.

Loren D. Grubb, formerly chemical process engineer for the Continental Oil Co., N. Y., is now assistant superintendent of the company's refinery at Ponca City, Okla.

L. W. Kanninen is now plant manager for E. J. Lavino & Co., Newark, Calif. He was previously superintendent of the Minnesota Mining & Manufacturing Co.'s plant at Corona, Calif.

W. R. Riggs has been appointed general superintendent of the Sinclair Research Laboratories, Inc., Harvey, Ill. Mr. Riggs received his B.S. degree in chemical engineering from Missouri School of Mines in 1932 and began work with Sinclair in the research laboratory. After gaining experience in laboratory and processing problems, he was put in charge of laboratory engineering and construction activities. In 1945 he was made division director in charge of pilot plants, and in 1949 he was named assistant general superintendent.

(*More About People on page* 58)

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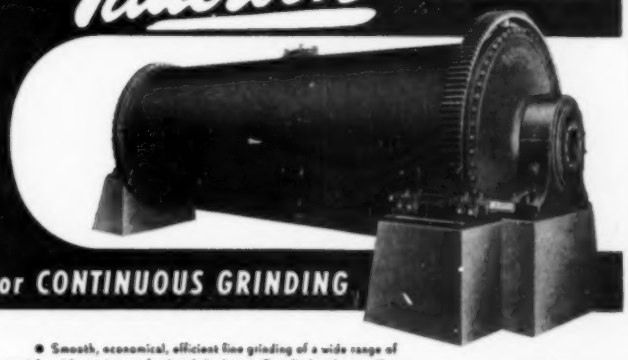

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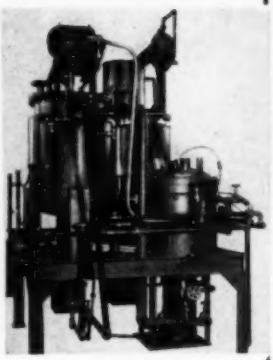

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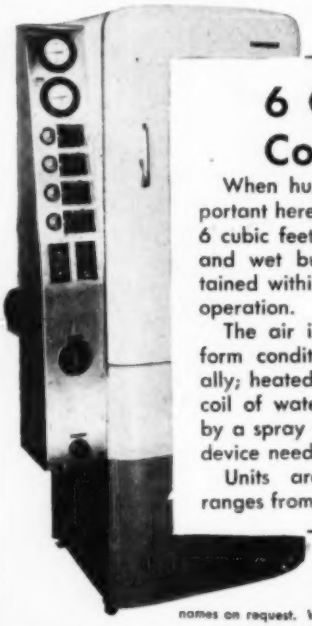

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PEOPLE

(*Continued from page 57*)

Alan S. Foust will head the department of chemical engineering at Lehigh University at Bethlehem, Pa., effective Feb. 1, 1952. He was formerly professor of chemical engineering at the University of Michigan, Ann Arbor, since 1948, and on the faculty of the department of chemical and metallurgical engineering since 1937 except for four years in active service in the Army.

Robert J. Koll, previously a chemical engineer for the B. F. Goodrich Chemical Co., Akron, Ohio, is now with the Diamond Alkali Co., Houston, Tex.

NEWTON WINS MEDAL INDUSTRIAL RESEARCH

Roy C. Newton, vice-president in charge of research, Swift & Co., has been named to receive the 1952 medal of the Industrial Research Institute, Inc. The medal has been awarded annually since 1945 for "outstanding accomplishment in leadership in or management of industrial research which contributes broadly to the development of industry or the public welfare." Official presentation of the medal will be made at the annual meeting of the institute to be held next May.

He is a graduate of Oklahoma Agricultural and Mechanical College and received his Ph.D. degree in chemistry from the University of Chicago in 1924. He joined the staff of Swift & Co. as a research chemist that same year and was appointed to his present position in 1941.

Robert S. Aries, consulting chemical engineer of R. S. Aries & Associates, is in Europe where he will spend six weeks visiting the company's European representatives and clients in France, England, Belgium, Switzerland and Western Germany. Dr. Aries was scheduled to present two papers, pertaining to synthetic rubber and petrochemicals, at the International Chemical Congress in Paris.

J. G. Bronson has been appointed divisional sales manager, barium and miscellaneous chemicals, Westvaco chemical division, Food Machinery and Chemical Corp. He was formerly assistant divisional manager, magnesium chemicals. This appointment became effective Jan. 1, 1952.

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C. P. Hackett

I. H. Munro

C. P. Hackett has been appointed assistant director of development in the Alkali section of The Solvay Process Division, Allied Chemical & Dye Corp., Syracuse, N. Y., and **I. H. Munro** has been named to succeed him as chief engineer.

Mr. Hackett has worked for Solvay since his graduation in 1923 from the Colorado School of Mines as a mining engineer. In 1936, he was appointed assistant chief engineer and in 1945, chief engineer.

Mr. Munro, a graduate of Colgate University, received his chemical engineering degree in 1934 from the Massachusetts Institute of Technology. He joined Solvay's engineering department in 1935 and was appointed assistant chief engineer in 1945.

AMUNDSON HEADS CHEM. ENG. AT MINNESOTA

At a recent meeting of the Board of Regents of the University of Minnesota, Neal R. Amundson was appointed head of the department of chemical engineering. Professor Amundson has been acting as head of the department during the last two years following the death of Prof. Charles A. Mann.

Professor Amundson received his B.S. in chemical engineering at the University of Minnesota in 1937 and then entered the employ of the Standard Oil Company of New Jersey, remaining with it until 1939. He then returned to Minnesota and joined the staff of the department of mathematics and mechanics. He earned his M.S. and Ph.D. degrees in 1941 and 1945, respectively. For a period during the war, he was at Brown University in the mathematics department.

Dr. Amundson is a member of several technical societies including the American Mathematical Society, and the Mathematical Association of America.

Reinhold H. Fritzsche, formerly in the research and development division of Merck & Co., Inc., Rahway, N. J., is now chief engineer for Chlorophyll, Inc., Neodesha, Kan.

Frederick A. Gilbert is now plant manager at the Buffalo Electro Chemical Co., Inc., Vancouver, Wash. He was formerly assistant to the vice-president of the company's plant in Buffalo, N. Y.

(More About People on page 60)

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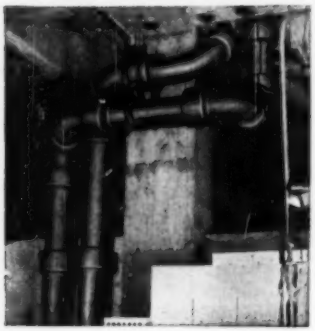

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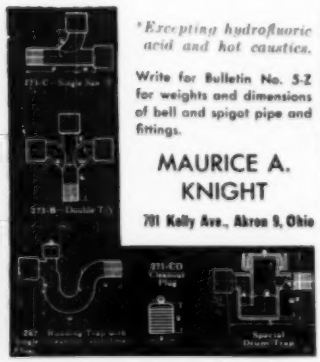

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PEOPLE

(Continued from page 59)

Charles F. Hauck has been appointed manager of sales promotion of the chemical plants division of Blaw-Knox Co., Pittsburgh, Pa. His duties will be the development of new markets and the direction of advertising and technical information. Mr. Hauck, who did his graduate work in chemical engineering at Case Institute of Technology, has had 15 years' experience in chemical engineering and water processing.

Thomas W. Booth is now an associate chemical engineer for the Texas Eastman Co., Longview, Tex. Mr. Booth, who has an M.S. degree from Virginia Polytechnic Institute, was formerly with the Tennessee Eastman Corp., Kingsport, Tenn.

B. Clifford Boswell, Jr., formerly a technical assistant in the plant development department of the Monsanto Chemical Co., Monsanto, Ill., is now a chemical engineer for the Holston Defense Corp., Kingsport, Tenn.

Robert B. Cragin is now the owner of the Cragin Oil Co., Rockford, Ill. He was previously vice-president of the Refinery Maintenance Co., Compton, Calif.

John B. Khu is now a chemical engineer for the Vern E. Alden Co., Chicago, Ill. He was previously technical director for Khu Yek Chiong (Sales Organization), Manila, P. I.

Hal L. Hollister, formerly an engineer in the nucleonics department of the General Electric Co., Richland, Wash., is now with the California Research & Development Co., Diablo, Calif.

J. L. Nelson, manager of B. F. Goodrich Chemical Co.'s plant at Louisville, Ky., recently received the Award of Honor for Distinguished Service to Safety from Capt. Estel Hack, managing director of the Louisville Safety Council. The plant consists of 57 buildings and covers approximately 60 acres.

Walter R. Pavelchek, Jr., has accepted a position as instructor in chemical engineeering at Tufts College, Medford, Mass. Mr. Pavelchek, previously a graduate student in chemical engineering at the University of Illinois, received his B.S. degree from Purdue University.

Robert H. Berg has been appointed process control engineer for the engineering division of International Minerals & Chemical Corp., Chicago, Ill. He is a graduate of the University of Minnesota and received his M.S. degree in chemical engineering from the University of Wisconsin. He has had several years of field and project engineering experience with the Fischer & Porter Co. and Panellit, Inc. Previously, he had been affiliated with the B. F. Goodrich Co., Goodyear Tire & Rubber Co., and the U. S. Naval Research Laboratories.

William P. Conant, Jr., formerly assistant supervisor for the Monsanto Chemical Co., St. Louis, Mo., is now salesman for the company in Cleveland, Ohio. He received his B.S. in chemical engineering from Purdue University.

Edward M. Cook is now an engineer for the Griscom-Russell Co. at Massillon, Ohio. He was formerly affiliated with the U. S. Rubber Co., in the Naugatuck chemical division, Naugatuck, Conn.

Joseph M. Fox, 3rd, previously water control engineer for Sharp & Dohme, Inc., Phila., Pa., is now with the M. W. Kellogg Co., Glen Ridge, N. J.

C. F. Gerald, formerly an assistant professor of chemical engineering at the University of Washington, Seattle, Wash., and an industrial consultant, is now associated with the Universal Oil Products Co., So. Michigan, Chicago, Ill. He received his D.S. from the Massachusetts Institute of Technology, Cambridge, Mass.

Walter E. Eisele, formerly assistant department head for Charles Pfizer & Co., Inc., Terre Haute, Ind., is now chemical engineer for the Chemstrand Corp., Wilmington, Del. He received his M.S. from the University of Michigan.

Ju-nam Chew, graduate student at the University of Texas, has been awarded a 1951-52 fellowship by the Humble Oil & Refining Co., Houston, Tex. Mr. Chew, who holds an M.S. in engineering and chemical engineering, is working for a Ph.D. in chemical engineering. He has had several years of experience as a teacher and research assistant at the University of Texas.

Charles G. Harford of Arthur D. Little, Inc., Cambridge, Mass., is in Cairo, Egypt, making a survey of low cost housing. The program has been set up under a bilateral agreement between the Egyptian and the United States governments, under the supervision of the U. S. Technical Cooperation Administration.

Robert L. Seitz is now employed as sales estimating engineer with Cochrane Corp., Philadelphia, Pa. He had been with Infilco, Inc., in Tucson, Ariz.

Alfred Lippman, Jr., is now general manager of the Commonwealth Engineering Co., Dayton, Ohio. He was formerly plant manager and superintendent of Bay Chemical Co., Inc., Weeks, La.

James J. Carberry is now a junior chemical engineer for the Du Pont Co., at its Eastern Laboratory, Gibbstown, N. J. He was a teaching fellow in the department of chemical engineering at the University of Notre Dame, where he received his B.S. in chemical engineering.

Albert E. Lewis, formerly a development chemical engineer with the American Viscose Corp., Nitro, W. Va., is now a junior engineer at the Diamond Alkali Co., Mentor, Ohio.

Frank A. Dudrow, Jr., is now assistant project engineer in the edible oil processing department of the Girdler Corp., Louisville, Ky. He was formerly associated with Fresse, Nichols & Turner, consulting engineers, at Houston, Tex., and received his B.S. from Texas A & M College.

Robert S. Herrod, formerly affiliated with the Hercules Powder Co., Wilmington, Del., is now the owner of Microfilming, Erie, Pa.

George W. Higginson, Jr., formerly in the plastics division of the Firestone Tire & Rubber Co., Pottstown, Pa., is now with the Attapulgus Clay Co., Camden, N. J., as supervisor of research and development.

Walter S. Kaghan is now a senior chemical engineer with Olin Industries, Inc., New Haven, Conn. He was formerly an associate professor at Rose Polytechnic Institute, Terre Haute, Ind.

Robert L. Lauren, formerly with the Diamond Alkali Co., Painesville, Ohio, is now a liaison engineer for the Douglas Aircraft Co., Santa Monica, Calif.

(Necrology on page 63)

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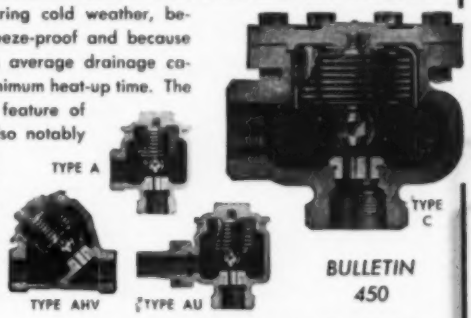

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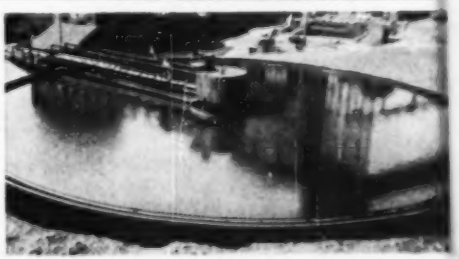

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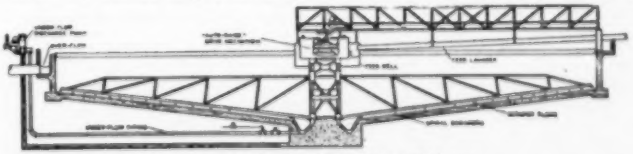

Cross section of a Hardinge concrete-tank Thickener.

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Necrology

R. J. FLETCHER

Robert James Fletcher, chief chemist of the AZO dye department of the American Cyanamid Co., Bound Brook, N. J., died recently after a short illness. He was a former research chemist with Du Pont Co. in Wilmington, Del., and was at one time chief chemist for the former Amalgamated Dye Stuffs & Chemical Works, Newark. Mr. Fletcher was graduated from Cornell University in 1917.

A. B. RAY

Arthur B. Ray, sales manager of the special products division of the Carbide and Carbon Chemicals Co., died Dec. 24, at the age of 62. Dr. Ray, who received his doctor's degree from Cornell University, joined Union Carbide and Carbon Corp., in 1919 as a research chemist, and subsequently became associated with Carbide and Carbon Chemicals Co., a division of Union Carbide. He was an authority on activated carbon, and also worked in the fields of inorganic, physical and industrial chemistry, rare earths, toxic inorganic materials, reactions between gases and incendiary and pyrotechnic materials.

G. H. SANFORD

G. Herbert Sanford, assistant mechanical superintendent at Du Pont's Belle Works plant at Charleston, W. Va., died recently. Mr. Sanford, who received his B.S. in chemical engineering from Syracuse University, had been with Du Pont since 1929. Until 1943, he was assigned to the ammonia department, Experimental Station, where he was responsible for design, construction and maintenance of all semiworks equipment. In 1943, he became associated with the Hanford plant's explosives department, where he was chief supervisor in the manufacture of an ingredient for the atomic bomb, which position he held until his most recent assignment in 1944.

C. R. POWERS

Clinton R. Powers, chief engineer, Delaware Rayon Co., Wilmington, Del., died Dec. 3, 1951. Mr. Powers, who received his B.S. in chemical engineering from Tufts College, was engaged largely in dye and rayon manufacture. For a number of years, he was in the Du Pont rayon division at Kenmore, N. Y., in a supervisory capacity. Subsequently he was with the Remington Arms Co., Bridgeport, Conn., and the Manville Jenckes Co., Woonsocket, R. I.

(*More Necrology on page 64*)

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NECROLOGY

(*Continued from page 63*)

J. B. EKELEY

John B. Ekeley, professor emeritus in chemistry at the University of Colorado, died Nov. 8, 1951, at the age of 81. Dr. Ekeley received his Ph.D. from the University of Freiburg, Baden, Germany, in 1902 and came to America where he was immediately appointed head of the department of chemistry at the University of Colorado. During World War I, he was instrumental in developing methods for the preparation of very pure tungstic acid from Colorado tungsten ores. Upon the resultant formation of the Tungstic Acid Corp., Boulder, Col., Dr. Ekeley supervised its industrial process. From 1909 he spent a year's sabbatical leave at the Sorbonne in Paris and at the University of Berlin. At international meetings of chemical societies Dr. Ekeley frequently was present as a United States delegate. He is the author of "A Laboratory Manual of Inorganic Chemistry," "The Chief Laws and Theories of Chemistry Brieny Stated," and various articles in American and European chemistry journals.

JAMES GARRETT VAIL

James Garrett Vail, retired vice-president of the Philadelphia Quartz Co. and former President of the American Institute of Chemical Engineers, died Dec. 11, in New Delhi, India. At the time of his death, Dr. Vail was working at an International Center for the American Friends Service Committee. He was 65.

President of the Institute in 1946, Dr. Vail also served as Vice-President in 1939 and 1940, and was elected to three terms as Director: 1932-34, 1936-38, 1941-43. During his administration as President the plans for launching this magazine were completed.

He joined the Philadelphia Quartz Co. in 1905 as a chemist, becoming chemical director in 1931, and a vice-president in 1940. An authority on soluble silicates and holder of many patents in the field, he was also the author of an A.C.S. monograph on Soluble Silicates in Industry. He recently completed the manuscript for a new volume on the subject.

He was a past chairman of the Philadelphia Section of the American Chemical Society, past chairman of the American Section of the Society of Chemical Industry, fellow of the American Institute of Chemists and of the American Ceramic Society, and a member of the Franklin Institute, University Club of Philadelphia, Chemists' Club, New York, and the Cosmos Club, Washington. In 1933 he received the Chemical Industry Medal from the Society of Chemical Industry for his work in the silicate field.

Dr. Vail was educated at Westtown School, University of Pennsylvania, Harvard University, and the Institute of Technology at Darmstadt. In 1946 he received an honorary Doctor of Science from Haverford College. He was born Nov. 16, 1886. In 1910 he married Ruth Russell of Cleveland, Ohio, who was with him in India. He has two sons, Benjamin and Philip.

* * * * * * *

We cannot help but add here our personal evaluation of Jim Vail. He meant much to us, being the President of the Institute during the planning year for "C.E.P." As we read the facts above, summarizing the scientific accomplishments of our friend, the thought strikes that important as they are, most of us who knew him will not think of them when we remember his life. The quality which set him apart from other men was that one felt, when talking to him, his immense spiritual qualities. Immortality was certain, God was, and man had a soul; all these shone through his every word and deed.

He had a faith big enough for others to lean on, and he had a belief which he carried into action through all his years. In 1920 he was in Germany with the American Friends Service Committee feeding children in cooperation with the Hoover Commission. In 1939 he went to Germany to study the problem of Jewish refugees. In 1941 he spent three months in Germany and occupied countries representing the American Friends Service Committee. In 1944 he was in India establishing relief-feeding stations, in 1947-48 he was in Africa and the Middle East working on international problems and conferring with Arab and Jewish leaders in hopes of a truce. This led to his appointment as an adviser to the U. N. mission in support of Count Bernadotte's efforts to restore peace in the Middle East.

At the time of his death, he was again engaged in helping others, this time in India, which he loved, and where he once talked with Gandhi of things of the spirit.

We had many quiet talks with Jim, and always one felt the sureness of his philosophy that:

Fierce though the fiends may fight
And long though the angels hide
I know that Truth and Right
Have the Universe on their side.

What more can one say than that Jim Vail loved and worked for his fellowman.

When one thinks of all he did in the few years he had on this earth, it brings happiness to think of what he is going to do with eternity.

F.J.V.A.

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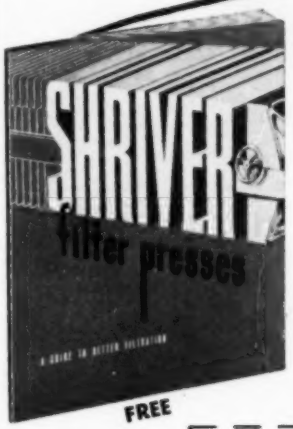

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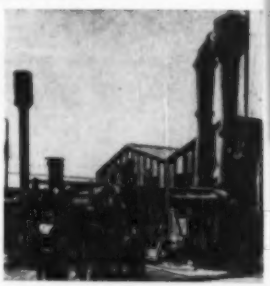

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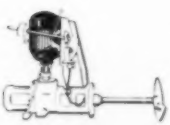

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